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Errata

Please note that the cover for Issue #1&2 of Transactions volume 98 (2005) presents an incorrect section title for the paper authored by Burke and Stratton and omits the paper authored by Tiemann, Szafoni, and Roman. The correct listing is shown below.

Earth Science Papers

Burke, J.T. and J.F. Stratton
Rugose Corals of the Livingston Limestone Member, Bond Formation, Coles and Edgar County, Illinois 145

Zoology Papers

Tiemann, J.S., R.E. Szafoni, and K. Roman
Freshwater Mussel (Bivalvia: Unionidae) Survey of Kyte River, Ogle County, Illinois 159

The manuscripts appears in the issue, beginning on page 145 for the Burke and Stratton paper and on page 159 for the Tiemann, Szafoni, and Roman article, however you may wish to correct this error on the back cover of your personal copy.

Issue 1&2 of 2006 now continues beginning on page 1 with the article by Ossum, Zwane, and Rhykerd.

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Plant Population Effects on Ecological Characteristics of Field Bean (*Phaseolus vulgaris* L.) in Swaziland

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ABSTRACT

Field bean (*Phaseolus vulgaris* L.) is one of the major grain legumes grown in Swaziland. Though there is a recommended spacing for this pulse, small-scale farmers plant it at any convenient spacing. They do not purposely vary the spacing to evaluate any changes in yield. Knowledge of the ecological characteristics of field bean in different populations might suggest new ways of establishing and managing this pulse. This investigation was conducted in Swaziland, in the 2004/2005 cropping season, to determine the effects of different intra-row spacing on weed density, disease and insect pest incidence, soil temperature, and crop yield. Five plant populations (400,000; 200,000; 133,333; 100,000 and 66,667 plants/ha) were investigated in a randomized complete block design, replicated four times. Although increasing the field bean population did not significantly decrease weed scores, the number of weed species did decrease as the canopy closed from 3 to 6 weeks after planting (WAP). A greater number of weed species invaded the less dense plant populations. Disease incidence increased with time in all plant populations. Soil temperatures did not significantly differ among plant populations. The 400,000 plants/ha population had a significantly ($P < 0.05$) higher seed yield (695.8 kg/ha) than the recommended plant population of 200,000 plants/ha (445.5 kg/ha). Therefore, small-scale farmers are advised to plant field bean at the spacing of 50.0 cm x 5.0 cm at the rate of 400,000 plants/ha.

Keywords: Weed density, weed suppression, soil temperature, field bean, ecological characteristics.

INTRODUCTION

Field bean (*Phaseolus vulgaris* L.) is an annual crop characterized by trifoliate leaves and white or purple flowers. In Swaziland, a popular recommended variety of field bean is the speckled, seed-type known as sugar bean (Anon., 1991). It is a rich source of proteins and contains about 20% more energy on a dry mass basis than bread; it is rich in vitamins A

and C (Norman, 1992). Because sugar bean is a legume, it will fix nitrogen in the soil through symbiosis. It is a short-season crop, usually maturing in 65–110 days after planting, and exhibits a rich diversity in seed characteristics, size, shape and color, growth habits and adaptative traits (van Schoonhoven & Voysest, 1993).

Field bean grows well in temperatures between 15°C and 30°C, with higher temperatures resulting in poor pod set (Norman, 1992). Soils suitable for growth of field bean are deep, well-drained, loamy soils, with a pH of 5.5 to 7.0. If the soil pH is below 5.5, liming is required, because beans are sensitive to high concentrations of aluminum and manganese (Norman, 1992). Field beans grow under an annual rainfall range of 700–1000 mm (van Schoonhoven & Voysest, 1993).

Plant population density is of great importance in the production of any crop. Attempts have been made by farmers to maximize field bean seed yield (Leakey, 1972). Quite often, small-scale farmers do not increase crop yield when they use the recommended population density, which is 200,000 plants/hectare with 10 cm between seeds (Duke, 1983). Maximizing the yield of field beans is very important; hence, it requires a review of the currently used plant population density in order to determine a population that could help to solve the problem of weed management, disease and insect pest incidence and low yield. Crop population density can influence weed density (Zimdahl, 1993). This investigation was undertaken to assess the effect of field bean population density on weed density, soil temperature, disease infestation, insect pest abundance and seed yield.

METHODS

Location and Experimental Design

This field trial was conducted at the University of Swaziland, Luyengo Campus (26°34'S, 31°12'E; 750 m above sea level; annual rainfall, 800 mm; mean annual temperature, 18°C), in the Crop Production Department Farm of the Faculty of Agriculture from December 2004 to February 2005. The soil type was the Malkerns M-set soil series that are dark, clay loam to sandy loam Oxisols (Murdoch, 1968). The experimental design was the randomized complete block design of five treatments, replicated five times. The five treatments were: 50.0 cm x 5.0 cm - 400,000 plants/ha; 50.0 cm x 10.0 cm (recommended spacing) - 200,000 plants/ha; 50.0 cm x 15.0 cm - 133,333 plants/ha; 50.0 cm x 20.0 cm - 100,000 plants/ha, and 50.0 cm x 30.0 cm - 66,667 plants/ha. In all cases, the inter-row spacing was 50 cm; the intra-row spacing was 5.0 cm, 10.0 cm, 15.0 cm, 20.0 cm and 30.0 cm, respectively. A 100-cm space was maintained between replicates, and 50 cm separated plots within each replicate. Plot sizes were 5.5 m x 4.0 m.

Fertilizer Application and Planting

Land preparation consisted of moldboard plowing to a depth of 46 cm followed by disking with a tractor-mounted disk harrow to a depth of 20 cm. Fertilizer application was made one day before planting. A basal application was made using a compound fertilizer, N:P:K [2:3:2 (22) + Zn] at the recommended rate of 400 kg/ha (Anon., 1991). The fertilizer was applied in bands 10 cm away from the rows and was mixed with the soil. The variety of the field bean used was 'PAN 159'. Seeds were hand-planted, using two seeds/station, on 18 December 2004. To enhance germination and emergence, plots were watered to field capacity using sprinkler irrigation for the first three days after planting.

Ten days after emergence each planting station was thinned to one plant to provide the desired populations per treatment.

Data Collection

Data were collected on weed infestation, disease incidence, insect pest infestation, and soil temperature.

Weed Infestation

Weed infestation was assessed at 3 and 6 weeks after planting (WAP). Weeks 3 and 6 were chosen because they represent two important dates in the agronomic management of the field bean and the likely relationship between the crop and its weeds. Weeding is often done in this crop at about 4 weeks after planting. By assessing the parameters investigated at one week before weeding, it would be possible to compare the ecological characteristics "before" (3 wks after planting) and "after" (6 wks after planting). The first assessment at 3 WAP was followed by the first weeding at 4 WAP using hand hoes. To assess weed density, a 50-cm quadrat was used and three assessments/plot were made on each occasion. The descriptions of the range of scores (1-6) that indicated the degree of weed density were: 1, zero weeds within the quadrat; 2, sparse weed coverage of soil within the quadrat; 3, intermediate weed coverage of soil within the quadrat; 4, general weed coverage of soil within the quadrat; 5, severe weed coverage of soil within the quadrat; and 6, complete weed coverage of soil within the quadrat. This method of estimating weed density has previously been used (Daisley et al., 1988; Orluchukwu & Ossom, 1988; and Ossom et al., 2001). The weed species were also identified and classified (Botha, 2001) within the quadrat at each determination. The distribution (relative abundance) of each species within the quadrat was evaluated and expressed as a percentage of all weed species within the quadrat. Ossom et al. (2001) and Ossom (2003) have used this method to assess weed infestation in sweetpotato [*Ipomoea batatas* (L.) Lam.] and cucumber (*Cucumis sativus* L.), respectively.

Disease Incidence

Also determined at 3 and 6 WAP, disease infestation within the 50-cm quadrat was assessed and scored (1-6) as follows: 1, no disease incidence on any parts of plants within the quadrat; 2, slight incidence of disease; 3, moderate incidence; 4, slightly severe incidence; 5, severe incidence; and 6, very severe incidence of disease in all parts of plants within the quadrat. The assessment focused on disease incidence rather than on disease identification. Three determinations/plot were made at each assessment. A similar method using a descriptive key that described plants with different levels of disease and assigned a category, number, index, grade or percentage to each description had been used by Balasubramaniam et al. (1993).

Insect Pest Infestation

Using the same scale of 1-6, insect pest infestation was assessed based on sighting of insect pests or the visual assessment of damage caused by insect pests on plants within the 50-cm quadrat. The focus of the exercise was not on insect identification, but on the physical presence of insects or insect damage found. The scale of scores was as follows: 1, no insect pest or insect damage on any plant part; 2, slight incidence of insect presence or crop damage; 3, moderate incidence of insect presence or crop damage; 4, slightly severe incidence of insect presence or crop damage; 5, severe incidence of insect or crop

damage; and 6, very severe incidence of insects or crop damage. As in weed and disease assessment, insect infestation was assessed at three locations/plot at 3 and 6 WAP. When scoring for weed infestation, disease incident and insect pest incident, three scores were averaged per plot and the mean was then used as the score for the respective parameters.

Soil Temperature

Soil temperature was taken every three weeks on a bright, sunny day without rain, and between 1400 and 1600 hours. The temperature was recorded using the Fisher brand bi-metal dial thermometers having a gauge diameter of 4.5 cm, a stem length of 20.3 cm, and an accuracy of ± 1.0% of dial range at any point on the dial (Ossom et al., 2001; Ossom, 2003). The temperature readings were taken at a distance of 10 cm from the plant rows, and at depths of 5 cm, 10 cm, and 15 cm. Three readings were made in each depth/plot, totaling nine readings/plot. In order to ensure that the thermometer sensor was stabilized, after inserting the thermometer into the soil, a 30-second interval was allowed to elapse before readings were taken.

Data Analysis

The statistical analysis technique applied was the analysis of variance (ANOVA) using MSTAT-C package, version 1.3 (Nissen, 1983). The least significant difference (LSD) test (Steel & Torrie, 1980) was used for mean separation at 5% probability level, unless otherwise indicated.

RESULTS AND DISCUSSION

Weed Infestation

Weed density showed no significant differences (Table 1) between field bean populations. However, all plant populations showed decreased weed density (as indicated by lower weed scores) later in the season (6 WAP) than earlier in the season (3 WAP), except for 66,667 plants/ha, which was slightly higher. This is likely because of the combined effect of weeding at 4 WAP and fewer weeds germinating later in the growing season. The highest plant population density (400,000 plants/ha) suppressed weeds (weed score, 3.3 at 6 WAP) better than the lowest plant population (66,667 plants/ha) that had weed a score of 3.5 at 6 WAP. Weed density data showed that the higher the field bean population was, weed density was also lower.

Row spacing could have a significant effect on the competition between field bean and weeds (Malik et al., 1993; Teasdale & Frank, 1983). Field bean planted in narrow rows might encourage crop competitiveness and could result in fewer and shorter weeds, resulting in improved crop yield (Malik et al., 1993; Teasdale & Frank, 1983). It has been reported that the canopy closed more rapidly as the distance between plants decreased; canopy closure shaded the soil and significantly slowed weed growth (Murdock et al., 1986; Teasdale & Frank, 1983). It is worth noting that controlling weeds prior to canopy closure is crucial in maximizing yields. Teasdale & Frank (1983) observed weeds that were allowed to emerge with field bean were only slightly suppressed. They concluded that in most cases weeds that emerged with the crop, prior to canopy closure, were likely to grow to maturity and had greater effect on yield. They further noted that when field bean were kept weed free for the first half of the growing season, weed growth was significantly reduced. Therefore, the reduction in weed scores from 3 to 6 weeks in this

study can be attributed to the closing of the plant canopy and the direct result of shading the weeds. Shading leads to decreased solar radiation reaching the weeds under the crop (Keeley & Thullen, 1978; Knake, 1972), which decreases carbohydrates and energy for survival. With time, the weeds could die or at best, grow poorly and give very little competition to the crop (Ossom, 2003). Weeds that are most competitive with crops usually have a high photosynthetic rate and rapid partitioning of photosynthates into new leaf production; they have a high light saturation intensity and a low carbon dioxide compensation point (Zimdahl, 1993). The coefficient of determination (R^2) of 0.017 indicated that 1.7% of the variation in seed yield/ha of field bean could be attributed to the adverse effect of weed density at 3 WAP. Zimdahl (1993) reported crop yield reduction among the detrimental effects of weeds. It had been stressed (Woolley & Davis, 1991) that weed management often requires maintenance of weeds at appropriate infestation levels, and not complete weed eradication. Thwala (2004) also reported significant differences between weed density and cropping systems that varied crop populations. Our results agreed with the reports of Thwala (2004) and Ossom et al. (2001) regarding the decrease of weed density as the cropping season progressed.

Weed Species Distribution

Table 2 shows the influence of plant population on weed species distribution at 3 WAP. The species were distributed over nine families and 12 genera. *Richardia brasiliensis* was the most abundant weed species (17.9-36.4%) at 3 WAP; this was closely followed by *Portulaca oleracea* (9.3-22.5%) and *Oxalis latifolia* (15.1-20.7%), respectively. These weed species also had higher weed scores in all the plant populations. *Elusine africana* was the least abundant weed species in all plant populations. At 6 WAP (Table 3), a greater diversity of weeds infested the plots than at 3 WAP. The species were made up of 15 genera distributed over 10 families. The three most dominant species at 6 WAP were *Richardia brasiliensis* (29.6-37.2%), *Oxalis latifolia* (20.0-37.2%), and *Cyperus rotundus* (6.1-27.8%). The weed species that were ubiquitous in all field bean populations were *Richardia brasiliensis*, *Oxalis latifolia*, *Cyperus rotundus* L. and *Bidens pilosa*. Though no clear pattern of the number of weed species was demonstrated in each field bean population, the lowest population had the highest number of weed species (14) at 6 WAP compared with the highest population having 11 species at the same period.

Differences in weed species relative abundance could be associated with a number of ecological factors: plant population, intensity of inter- and intra-species competition for scarce resources, and ecological requirements of different species, to name a few. A low plant population initially results in more space between plants in a plot. The consequence could be that light penetration in such a plot would be greater than in a densely populated plot. With more light available between plants in the sparsely populated plots, it is likely that different weed species would readily establish as seen in the lowest bean population. The converse would be true in a densely populated plot (e.g., the 400,000 plant/ha). This might be associated with the crop's adaptive plasticity – the frequency of branching, internode increases, and direction of growth in response to light or nutrient levels (de Kroon & Hutchings, 1995; Linhart & Grant, 1996; Alpert & Simms, 2002).

The Canola Council of Canada (2005) reported that weed competition reduced canola (*Brassica rapa* L.) plant growth and leaf area resulting in increased flower, pod and seed abortion. The report further noted that the yield loss due to weeds could vary widely from

year to year, depending on several factors that included density and spatial arrangement of the crop; species and density of the weeds; relative competitiveness of crop and weeds; relative time of emergence of crop and weeds, and the availability of moisture and nutrients. Amador-Ramirez (1999) reported that weed seedlings that emerged with dry bean or soon after, were a major problem because they interfered with crop growth and development more than weeds that emerge later. Much of the harm that weeds do to agricultural crops is from competition, and for many years, scientists have tried to provide a scientific explanation for plant competition (Black et al., 1969), but have not entirely succeeded.

Disease Infestation

Disease infestation did not significantly vary between the field bean populations (Table 1). However, both the recommended plant population (200,000 plants/ha) and the highest plant population (400,000 plants/ha) showed a similar degree of disease incidence (disease scores of 1.2 and 1.3, respectively). The lowest plant population (66,667 plants/ha) and 133,333 plants/ha had the same disease score of 1.3. The plant population that was 50% (100,000 plants/ha) of the recommended plant population showed the disease score of 1.4, which was not significantly higher than the recommended population.

Diseases have been reported to be the leading constraint to increased field bean production throughout the world (Kelly & Miklas, 2005). None of the levels of infestation observed in this investigation posed a serious threat to field bean production. That disease scores were not significantly different among the plant populations could be associated with the likely absence of damaging proportions of virulent pathogens in field bean plots when this investigation was conducted. This indicates that diseases did not seriously affect the crop. Probably, under the conditions of this investigation, disease incidence was not dependent on the plant population of the field bean crop. However, Anon. (2005a) reported that increased plant population significantly increased white mold (caused by *Sclerotinia sclerotiorum*) incidence in Minnesota. Disease-causing organisms have been reported (Zitter, 1987; Hoffman & Zitter, 1994) to be harbored by weeds, with the resultant decrease in crop yields. It would be expected that too many plants/ha could interfere with efficient cultural management practices in the plots. Where humid and warm weather prevails, there could be a possibility that increased plant populations could predispose a crop to higher incidence of disease infestation, especially by fungal pathogens. Such disease infestation eventually could reduce crop yield.

Insect Pest Infestation

Slightly higher insect pest incidence occurred at 6 WAP than at 3 WAP in all plant populations (Table 1). At 3 WAP, there were no significant differences in the level of insect pest incidence in all plant populations (Table 1). However, at 6 WAP, plants in the most dense plant population (400,000 plants/ha) had a significantly higher ($P < 0.05$) level of insect pest infestation (score, 4.3) than plants in the recommended plant population (200,000 plants/ha: score, 3.7). Plant populations below the recommended populations did not show any significant difference in their insect pest incidence.

The observed trend, that increasing plant population density resulted in increased insect pest incidence, was consistent with the reports of Ehrensing et al. (1997), which noted that *Scaptomyza* fly populations might buildup with increased hectares of meadowfoam (*Limnanthes alba*) cultivated. Litsinger and Moody (1976) pointed out that multiple

cropping (that leads to increased plant populations/ha) could increase, or decrease the incidence of an insect or disease, or the population of its natural enemies, depending on the component species in the mixture, and the pest or disease concerned. The University of Sydney (2004) reported that "clean farming", in which there is zero tolerance for weeds and debris, destroys over wintering locations and alternative food sources such as pollen and nectar in flowering weeds, thus limiting the populations of predators and parasites. Denser crops stand (higher plant population) harboring a large number of insect pests could lead to increased damage to crop leaves, stems and yield components. Eventually, crop yield could be adversely affected if higher plant populations attracted an increased number of insect pests. However, Karel (1993) reported that flower and pod damage by insect pests decreased when plant populations increased from 66,666 to 1,333,333 plants/ha in mixed cropping that involved common beans and maize. In another study, Karel (1991) reported a reduced incidence of bean flies (*Ophiomyia phaseoli* Tryon, *O. centrosematis* de Meijere, and *Melanagromyza spencerella* Greathead) on common beans when plant population was increased from 66,666 to 533,332 plants/ha in mixed cropping. It should be borne in mind that the ecological situations in mixed cropping are often quite different from those in sole cropping, the cropping system that we used when studying field bean populations.

Soil Temperature

Soil temperature (Table 4) did not show any significant differences between field bean populations. However, temperatures at 5-cm depth were generally higher in all plant populations than temperatures at 10-cm and 15-cm depths.

The observation that soil temperature was higher at 5-cm depth than at 10- and 15-cm depths agreed with earlier observations (Ossom et al., 2001; Ossom, 2003; Thwala, 2004; Dlamini, 2005) who also reported that soil temperature was lower at greater depths. Soil temperature has been reported to influence some physiological processes including seed dormancy and germination (Relf, 1997), seedling emergence and growth (Anon., 2004). Davis et al. (1990) reported that field crops grow at a range of 5-30°C soil temperature, noting that soil temperatures above the annual soil temperature range could cause flower blast. It was reported that increased soil moisture, subsoil compaction, and decreased soil temperature may result in insufficient early season transplant root development that decreases uptake and/or immobilization of essential nutrients (Mellish, 1978; Bockus & Shroyer, 1998). The soil temperature range (25.7-28.5°C) recorded in our investigation was consistent with soil temperatures in tropical areas (Sanchez, 1976; Ossom et al., 2001; Ossom, 2003).

Among the possible reasons that might be advanced for higher soil temperatures at 5-cm depth than at lower depths are the following: greater solar radiation impacts the soil nearer the soil surface; greater microbial activities in the topsoil where the higher organic matter content might enhance microbial life; greater intensity of physiological activities (respiration, decay, and/or fermentation) caused by plant roots and other macro-organisms (flora and fauna alike) in the soil, less soil moisture compared to lower depths of the profile where the water table is deeper than at the soil surface; and reduced air circulation in the soil environment than in the atmosphere.

Field Bean Yield

Figure 1 shows the seed yield (dry mass) of field bean. There was a positive interaction ($P < 0.05$) between plant population and total seed yield and a positive correlation between plant population and seed yield. The plant population of 66,667 plants/hectare had a significantly ($P < 0.05$) lower total seed yield (270.4 kg/ha) than the 400,000 plants/ha plant population (695.8 kg/ha).

Though seed yields in this investigation were quite low compared to those of other workers (Crothers & Westermann, 1976; Ayaz et al., 2001; Clark & Carpenter, 2005), plant population density, nevertheless, contributed to the total seed yield of the crop. The results obtained in this experiment showed a positive response of higher seed yield with higher plant population densities. These results were in agreement with the findings of other workers (Crothers & Westermann, 1976; Shirtliffe & Johnston, 2002) that high plant population in *Phaseolus vulgaris* led to higher seed yield. The effect of plant population on seed yield was also consistent with the data of Ayaz et al. (2001) who reported that seed yield approximately doubled as population increased from 100,000 to 400,000 seeds sown per ha. Ayaz et al. (2001), and Herbert and Hill (1978) reported that as plant density increased, intensity of interplant competition also increased, and yield/plant would decline, although total yield/unit area might increase. Anon. (2005b) stressed that dry beans in all market classes had the potential for higher yields with narrower spacing (higher plant populations). In cowpea [*Vigna unguiculata* (L.) Walp.], such higher yield was explained to be an indication of responsiveness to higher planting densities (Ismail & Hall, 2000).

CONCLUSION AND RECOMMENDATION

While increasing the planting population density did not significantly reduce weed scores at the 0.05 level of significance, there was a trend toward fewer weeds when the field bean plant canopy closed from 3 to 6 WAP. Both the recommended plant population (200,000 plants/ha) and the highest plant population (400,000 plants/ha) showed the same degree of disease incidence. Soil temperatures were higher at 5-cm depth than at lower depths but showed no significant differences among plant populations. It is recommended that for higher seed yields, the higher population of 400,000 plants/ha (spacing, 50.0 cm x 5.0 cm) be adopted by small-scale farmers. More long-term studies should be done to clearly identify the influence of field population on the parameters investigated in this study.

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Table 1. Influence of field bean population on mean weed, disease, and insect incidence.

Field bean population/ha	Weed score		Disease score		Insect score	
	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]
400,000	4.2	3.3	1.0	1.3	2.4	4.3
200,000	4.3	3.6	1.0	1.2	2.3	3.7
133,333	4.2	3.1	1.0	1.3	2.0	3.6
100,000	3.6	3.3	1.0	1.4	2.1	3.5
66,667	3.4	3.5	1.0	1.3	1.8	3.2
Mean	3.9	3.4	1.0	1.3	2.1	3.7
$LSD^{2}_{(0.05)}$	0.9	0.5	NA	0.3	1.0	0.5
Significance	ns	ns	NA	ns	ns	**

[1] Weeks after planting; [2] Least significant difference; ns, not significant at $P > 0.05$
**Significant at $P < 0.01$; NA, value not available

Table 2. Effects of plant population on weed species distribution at three weeks after planting.

Family name	Scientific name	Common name	Field bean population (plants/ha) and weed species relative abundance (%)[1]				
			400,000	200,000	133,000	100,000	66,667
Amaranthaceae	*Amaranthus hybridus* L.	Common pigweed	3.4	0.8	3.3	4.6	1.3
Asteraceae	*Bidens pilosa* L.	Blackjack	10.6	10.4	8.2	6.3	12.4
Asteraceae	*Schkruhria pinnata* L.	Dwarf marigold	2.6	0.4	0.0	1.3	0.9
Commelinaceae	*Commelina benghalensis* L.	Benghal wandering Jew	4.7	5.0	3.3	2.1	7.1
Cyperaceae	*Cyperus rotundus* L.	Purple nutsedge	17.0	17.9	17.6	11.0	9.8
Oxalidaceae	*Oxalis latifolia* H.B.K.	Red garden sorrel	17.5	19.2	17.2	20.7	15.1
Poaceae	*Cynodon dactylon* L.	Bermuda grass	3.0	0.00	1.6	3.4	0.4
Poaceae	*Paspalum distichum* L.	Couch paspalum	0.0	0.0	3.3	3.0	1.3
Poaceae	*Elusine africana* L.	African goose grass	0.4	0.0	0.0	0.0	0.0
Portulaceae	*Portulaca oleracea* L.	Common purslane	20.0	22.5	21.7	18.6	9.3
Rubiaceae	*Richardia brasiliensis* Gomes.	Tropical Richardia	19.6	17.9	18.0	27.4	36.4
Tiliaceae	*Corchorus olitorius* L.	Torsa jute	1.3	5.8	5.7	1.7	5.8
Number of weed species	NA	NA	11.0	9.0	10.0	11.0	11.0
Weed score[2]	NA	NA	4.2	4.3	4.2	3.6	3.9

[1] Because of rounding up of percentages, the totals may not equal 100.0%.
[2] Other analyzed values for weeds at 3 WAP are in Table 1.
NA, Not applicable

Table 3. Effects of plant population on weed species distribution at six weeks after planting.

Family name	Scientific name	Common name	Field bean population (plants/ha) and weed species relative abundance (%)[1]				
			400,000	200,000	133,000	100,000	66,667
Amaranthaceae	*Amaranthus hybridus* L.	Common pigweed	0.0	2.5	1.3	3.5	2.5
Asteraceae	*Schkruhria pinnata* L.	Dwarf marigold	0.4	0.0	0.0	1.2	0.0
Asteraceae	*Galinsoga parviflora* L.	Gallant soldier	0.4	4.1	0.8	1.2	1.3
Asteraceae	*Bidens pilosa* L.	Blackjack	7.7	11.6	5.9	12.3	4.2
Commelinaceae	*Commelina benghalensis* L.	Benghal wandering Jew	0.4	2.1	2.9	0.0	0.4
Cyperaceae	*Cyperus rotundus* L.	Purple nutsedge	27.8	11.6	18.9	6.1	22.1
Oxalidaceae	*Oxalis latifolia* H.B.K.	Red garden sorrel	26.5	24.4	29.8	37.2	20.0
Poaceae	*Cynodon dactylon* L.	Bermuda grass	0.0	0.0	0.0	0.0	1.7
Poaceae	*Paspalum distichum* L.	Couch paspalum	0.4	0.8	0.5	0.0	2.9
Poaceae	*Digitaria senquinalis* L.	Crab finger grass	4.3	2.5	2.1	3.8	4.2
Poaceae	*Elusine africana* L.	African goose grass	0.9	1.2	0.0	0.0	5.0
Portulaceae	*Portulaca oleracea* L.	Common purslane	0.4	0.0	1.7	0.4	4.6
Rubiaceae	*Richardia brasiliensis* Gomes.	Tropical Richardia	30.8	37.2	35.7	33.3	29.6
Solanaceae	*Datura stramonium* L.	Bitter apple	0.0	1.2	0.0	0.4	0.8
Tiliaceae	*Corchorus olitorius* L.	Torsa jute	0.0	0.4	0.4	0.4	0.8
Number of weed species	NA	NA	11.0	12.0	11.0	11.0	14.0
Weed score[2]	-	-	3.3	3.6	3.1	3.3	3.5

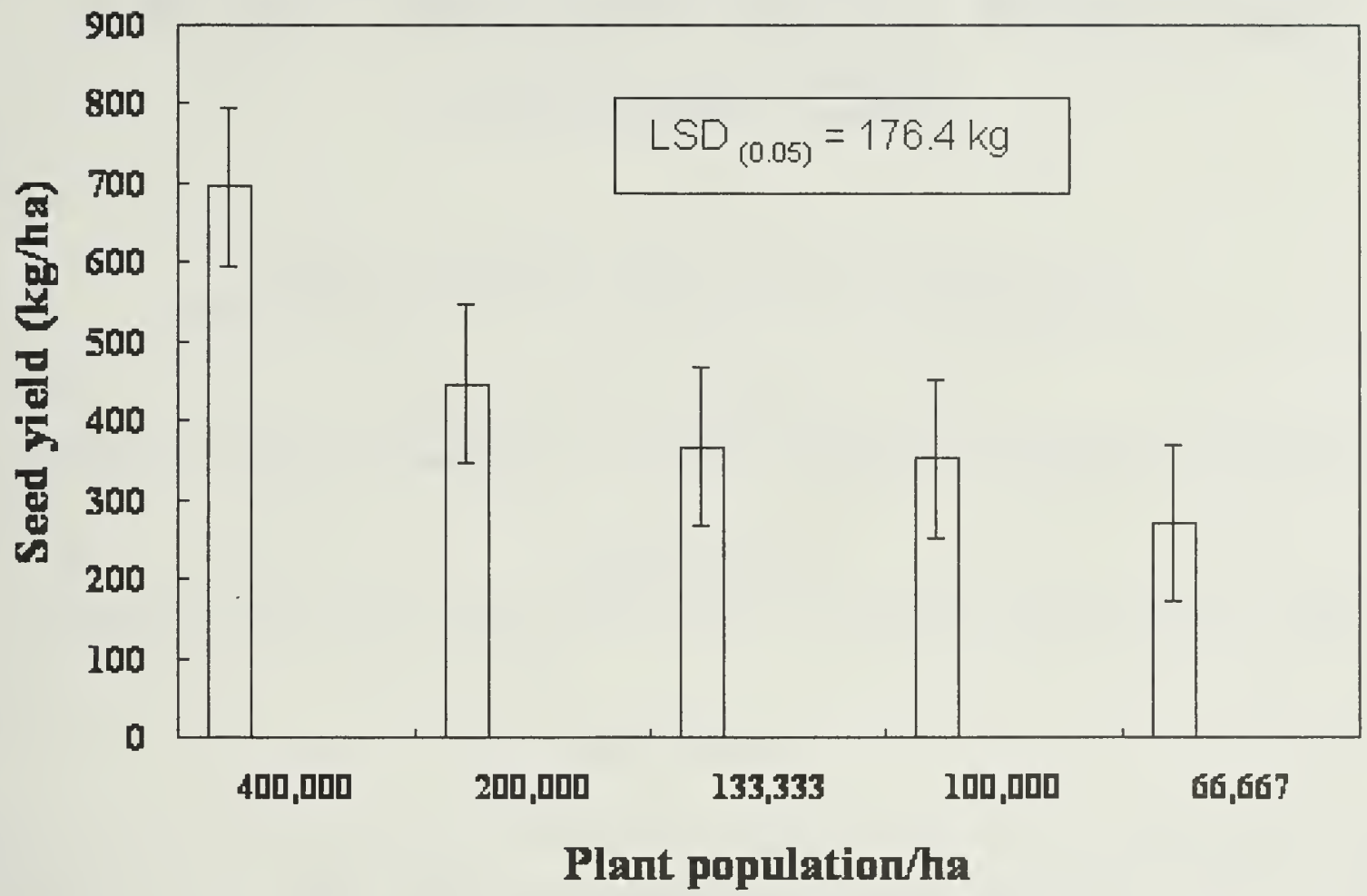
[1] Because of rounding up of percentages, the totals may not equal 100.0%.
[2] Other analyzed values for weeds at 6 WAP are in Table 1.
NA, Not applicable

Table 4. Effects of field bean population on soil temperature (°C) at 5-cm, 10-cm, and 15-cm depths.

Field bean population/ha	Soil temperature at 5-cm depth		Soil temperature at 10-cm depth		Soil temperature at 15-cm depth	
	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]
400, 000	27.8	27.8	27.3	27.2	26.3	26.4
200, 000	27.6	27.5	26.9	26.8	25.9	25.8
133, 333	27.3	27.3	27.1	27.1	26.2	26.0
100, 000	28.2	28.5	27.2	27.5	25.8	25.7
66, 667	27.7	27.9	27.5	27.3	26.1	26.3
Mean	27.7	27.8	27.2	27.2	26.1	26.1
$LSD^{3}_{(0.05)}$	0.7	1.0	0.5	0.8	0.6	1.0
Significance	ns	ns	ns	ns	ns	ns

[1] Weeks after planting
[2] Least significant difference
ns, not significant ($P > 0.05$)

Figure 1. Effects of plant population on field bean seed yield.



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Distribution and Reproductive Potential of Kudzu (*Pueraria lobata*, Fabaceae) in Illinois, USA

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ABSTRACT

Kudzu [*Pueraria lobata* (Willd.) Ohwi] was planted widely in the southeastern United States in the late 1930s to early 1940s, and now covers an estimated 3 million ha. The objective of this study was to evaluate the distribution and reproductive potential of kudzu seeds in Illinois. First collected in Illinois in 1941, a total of 78 populations of kudzu from 28 Illinois counties were recorded by 1997. In the southern third of the state, 75% of the populations were found, although one was located in Rock Island County (40° 30' N), about 110 km south of the Wisconsin border. Of the populations examined, most were very small with a mean area of 1.6 ha for all populations, although one exceeded 16 ha. All populations flowered during the summer of 1997, and mature fruit containing seeds were observed in six populations. Two color types of kudzu seeds (mottled vs. uniformly colored) were found, with the mottled seeds having greater mass than the uniform ones. Both scarified and nonscarified seeds of the two color types germinated over a series of constant temperatures ranging from 20° to 35°C; percentage germination was highest (94-100%) for scarified/mottled seeds at all temperatures. Vigorous seedlings developed from kudzu seeds, especially if the seeds were scarified and mottled, indicating that kudzu has the potential to reproduce from seed in Illinois.

INTRODUCTION

Pueraria lobata (Willd.) Ohwi (kudzu), a climbing woody vine of the family Fabaceae, is native to eastern Asia. Some authors consider the scientific name of this taxon to be *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & Almeida (Ward, 1998). This taxon was introduced into the southeastern United States in the 1870s when it was used as an ornamental, as a forage crop, and for its edible root. By the late 1930s and early 1940s, it was being planted extensively throughout the southeastern United States for erosion control (Shurtleff and Aoyagi, 1977). Since its introduction, kudzu has extended its range into the northeastern United States, and now occurs in New York,

Massachusetts, New Jersey, Ohio and Pennsylvania (Sorrie and Perkins, 1988; Frankel, 1989; Watson, 1989; Gleason and Cronquist, 1991). Mohlenbrock (1986) reported that kudzu occasionally was adventive in the southern half of Illinois.

Kudzu is identified easily by its large, alternately arranged, trifoliate leaves with ovate to subrotund, often slightly palmately lobed leaflets, and by its racemes of fragrant reddish-purple flowers that develop in late summer and early fall (Gleason and Cronquist, 1991). Its fruits are 4-12 cm long legumes with papery pubescent valves that contain 1-9 seeds having a thick, hard seed coat. The seeds may remain viable within the soil for several years before germinating (Everest et al., 1991).

Seed viability may relate to seed polymorphism where seeds of a species exhibit two or more distinctly different morphologies in size, shape, or color (Baskin and Baskin, 1998). These morphologic differences may be due to genetics or to the preconditioning environment during seed development. Seed polymorphism occurs in other legume species, including *Senna obtusifolia* (Baskin et al., 1998). Reports of seed polymorphism in kudzu were not found. Seeds of the same species with different polymorphs also may differ in their germination and their needs to break seed dormancy (Baskin and Baskin, 1998; Baskin et al., 1998).

Kudzu has a hard, leathery seed coat and requires scarification for maximum germination (Tabor, 1949; Tsugawa et al., 1979; Baskin and Baskin, 1998; Susko et al., 1999). For seeds collected in Raleigh, North Carolina, Susko et al. (1999) reported that scarified seeds germinated over a wide range of alternating temperatures (15°/6° to 35°/25°C with 12 hours at each temperature in continuous darkness) with no differences between dark vs. light/dark photoperiods. Optimal pH for germination was between 5.4 and 7 with decreased germination at lower or higher pH (Susko et al., 1999). Seeds germinated best at planting depths of 0.5-4.0 cm in well-watered, but not flooded, conditions (Susko et al., 1999).

Once established, kudzu vines have extraordinary growth rates with growth of 18 m in a single growing season being common (Shurtleff and Aoyagi, 1977). Vines originate from large tuberous roots that can grow to a depth of 3.5 m, and sometimes weigh 90-140 kg (Miller and Edwards, 1983). Numerous vines may grow from a single root crown. Vines spread in all directions and often root at nodes in contact with the soil, thereby forming new plants (Miller and Edwards, 1983). Kudzu can grow on a variety of soil types, achieving maximum growth on deep loamy soils (Everest et al., 1991).

Kudzu now covers an estimated 3 million ha of land in the United States, resulting in high economic losses by decreasing productivity on agricultural and forest lands (Bartlow et al., 1996; Pappert et al., 2000). Kudzu occasionally is responsible for disruption of electrical power, since it readily climbs over utility poles and power lines (Flint, 1983). Kudzu forms thick dense mats of vines that smother underlying vegetation. As a consequence, kudzu prevents the growth of other plant species, decreases plant species diversity, and also decreases the amount and variety of food available for wildlife (Miller and Edwards, 1983).

Kudzu was first reported and collected in Illinois in 1941 at the Trail of Tears State Forest, Union County (collected by G.D. Fuller #590, 24 Oct. 1941). Jones and Fuller (1955) reported kudzu from Jackson and Union Counties, while Mohlenbrock and Ladd (1978) found kudzu in seven counties, mostly in southern Illinois. The present study was conducted to determine the current distribution of kudzu in Illinois, and to assess the ability of kudzu to reproduce by seed obtained from one Illinois population.

MATERIALS AND METHODS

Kudzu populations in Illinois were located using information provided by natural heritage biologists, foresters, and other personnel in the Illinois Department of Natural Resources and the Illinois Natural History Survey, and by examining herbarium specimens from most of the state herbaria. All known kudzu populations in Illinois were visited during late summer and fall of 1997, at which time the location, total area, and the habitat were recorded. For each kudzu population observed, the total area of the population size was estimated by determining the distance along one side and estimating the distance through the middle of the population. The size of large populations was estimated visually from a helicopter. At five sites, two or three of the largest stems encountered were cut and their ages determined by counting growth rings.

Mature fruits were collected from six populations in central (Fayette and Jefferson Counties) and southern (Jackson and Union Counties) Illinois. Fruit production was generally low, and at five sites all fruits found attached to the vines were collected. At one site (Union County Fish and Wildlife Area) fruits were numerous, and 9-15 were selected randomly from each of 84 inflorescences from one vine. Fruit length, fruit width, and the number of seeds per fruit were determined from 25 randomly selected fruits from each population. The seeds exhibited two distinct types of seed coat color, one white to light gray with black markings (mottled), and the other a solid light brown without markings (uniformly colored). Thus seeds were sorted into two types based upon these visual differences.

Only the seeds from the Union County Fish and Wildlife Area were used to assess seed size, germination, and seedling characteristics. The two seed color types were kept separate and stored at 3°C until subjected to germination trials in spring 1998 and emergence trials in spring 1999. Seed mass and volume were determined for 100 seeds of each color type (four replications of 25 seeds each). Lots of 25 seeds were used rather than single seeds to improve precision in measurement. Percentage of floating vs. sinking seeds was determined for 100 seeds of each color type with no replication to give an indication of seed viability. More specific replicated tests of seed vigor were done via evaluations of germination over time and seedling development.

Percent seed germination was determined at four constant temperatures (20°, 25°, 30° and 35° C) using 50 seeds (five replications with 10 seeds each) for each of four treatments (scarified/mottled, scarified/uniform, nonscarified/mottled, nonscarified/uniform) at each temperature regime. Thus, the design included 4 temperatures X 2 seed types X 2 scarification treatments. All seeds were soaked initially in a 10% sodium hypochlorite (Clorox$^{\geq}$) solution for 10 minutes, and rinsed. After the rinse, half of the seeds of each seed coat color type were scarified with a razor blade by nicking the seed coat on the side

opposite the hilum. Then seeds were placed in glass petri dishes on three sheets of filter paper (Whatman #1) moistened with 5 ml water. Dishes were arranged randomly inside a clear Rubbermaid≥ container (35 cm x 24 cm x 12 cm) and placed in a dark growth chamber at appropriate temperature. Germinated seeds were counted daily for 14 days. A seed was considered germinated when the radicle emerged from the seed coat by ≥ 2 mm.

For seedling characteristics, seeds were soaked in a 10% Clorox≥ solution for 10 minutes, rinsed and planted to a depth of 1 cm in a standard greenhouse soilless mix (1:1:1 of peat/vermiculite/perlite) in plastic trays (27 cm x 19 cm x 6 cm). Each of five trays (replications) included four rows of planted seeds with 10 seeds/row. Individual rows contained seeds from one of four scarification/seed color treatments: scarified/mottled, scarified/uniform, nonscarified/mottled and nonscarified/uniform. Thus, the design included 2 seed types X 2 scarification treatments. Seeds were planted 1.75 cm apart within the row and rows were separated by a distance of 5.5 cm. Trays were placed initially in a growth chamber at a constant temperature of 25°C with a light intensity of 250 umol/s/m^2 which was the maximum intensity available in the chamber. Trays were moved to a growth room where temperatures ranged from 15.5° to 22.4°C, light intensity was 145 umol/s/m^2 (which was maximum intensity available within room), and relative humidity ranged from 32 to 46% as measured with a hygrothermograph. A photoperiod of 16-hrs light/8-hrs dark was maintained in both the chamber and the growth room. All trays were watered as needed with equal volumes. Plants were grown for one month (12 February to 12 March 1999). Growth was considered to begin at the start of imbibition when the seeds were first watered. Emergence, height of the stems (from soil surface to terminal bud on main stem), number of nodes, total leaf area (using a Li-Cor Model 3100 leaf area meter), fresh mass of shoots and dry mass of shoots (dried at 75°C for 48 hrs) were measured at the end of the experiment.

Data were analyzed using Excel (2002) or CoStat (1995). Means and standard deviations or standard errors were calculated. Where replicated data were available, analysis of variance was used to determine which means were significantly different.

RESULTS

A total of 78 kudzu populations from 28 counties were found in Illinois, 75% of which were located in the southern third of the state (Table 1 and Fig. 1). One population was found in Rock Island County (40° 30' N), about 110 km (70 miles) south of the Wisconsin border, and 110 km northwest of the closest known population in Peoria, Illinois (Fig. 1). Populations varied in size from 0.1 ha to more than 16 ha with an average of 1.6 ha.

Although most of the kudzu populations examined rarely exceeded 1 ha in size, one population that was located in Pope County, Illinois, in the extreme southern part of the state, exceeded 16 ha. This population from the Shawnee National Forest covered a 6 ha field that originally contained wildlife food plots and 10 ha within an adjacent mature pine plantation and oak/hickory forest. The field was impassible due to a tangle of kudzu vines. As many as 30 stems were counted rising from one tuberous crown. One stem found growing on the forest floor exceeded 50 m in length. It had rooted at some of the nodes and had developed aerial stems that grew into the canopy. No mature fruits were found at this site.

In our study, stems with a diameter at breast height (dbh) of 6 cm were encountered with 7 growth rings. These large stems were from the kudzu population in the Shawnee National Forest, but stems in excess of 3 cm dbh, with 2-4 growth rings, also were found in Schuyler County in west-central Illinois.

Most kudzu populations were found along roadsides, in successional fields, around farm ponds, in strip-mined areas, around home sites and other disturbed areas, indicating many had been planted or established as a result of earth moving and road building activities (Table 1). Of 17 land owners interviewed, one obtained young plants from the Soil Conservation Service, four got plants or cuttings from established populations, five were planted along township roads for erosion control, and seven were not sure where or how the populations became established.

Mature fruits were found in six of the 78 populations. Most of the fruits contained at least one seed, although occasionally fruits lacked seeds (Table 2). Fruit size ranged from 34-104 mm long, and 4.5 to 9.3 mm wide (Table 2). Fruits from Union County Fish and Wildlife Area were longest and contained the most seeds (Table 2). Two distinct seed coat color types (mottled vs. uniform) were found in the fruits from two-thirds of the populations producing fruit. The frequency of mottled seeds varied from 0 to 80% (Table 2). In the Union County Fish and Wildlife population, where numerous seeds were available, mottled seeds possessed a greater mass than uniform ones (for 25 seeds), although volumes were similar for both seed types (Table 3). A smaller percentage of mottled seeds floated when placed in water than did uniform seeds (3 vs. 73%) in an unreplicated trial. This difference indicated that mottled seeds were more apt to be viable than uniform ones. Intermediate forms that were light brown with black mottling were very rare (less than 1%), while the placement of mottled and uniform seed in the fruits was random (personal observations).

Mottled/scarified kudzu seeds from the Union County Fish and Wildlife Area population displayed germination percentages in excess of 90% at all four temperatures. For scarified seeds, mottled seed germination percentages were significantly higher than those for uniform seeds (Table 4). Nonscarified seeds had relatively poor germination, always less than 33%. Germination of nonscarified seeds was not significantly correlated to mottling except at 30°C. Scarification significantly improved germination for mottled seeds, but had no significant impact upon uniform seeds (Table 4). Germination rates declined at 35°C relative to other temperatures tested (Fig. 2). Most seeds germinated within 3 days of imbibition (Fig. 2). Overall, kudzu seeds that were uniform or nonscarified had lower germination.

Seedling characteristics were studied for plants grown from seed collected at the Union County Fish and Wildlife Area (Table 5). The number of surviving seedlings present at one month after planting was highest for scarified/mottled seeds (76%), lower for nonscarified/mottled seeds (32%) and lowest for uniform seeds regardless of scarification treatment. Heights, node numbers, leaf areas, fresh masses and dry masses were greatest for seedlings derived from scarified/mottled seeds (Table 5). For all seedling parameters measured, plants started from mottled seeds were more vigorous than those from uniform seeds. For seedlings from mottled seeds, plants from scarified seeds grew better than

from nonscarified seeds. The young seedlings from scarified/mottled seeds had relatively short main stems with an average length of 13.9 mm at day 30, while the shoots formed a carpet-like covering of leaves (area of 39.6 cm^2) in the trays. In contrast, seedlings of nonscarified/mottled seeds had main stems that were only 8.8 mm long, and a leaf area of only 5.1 cm^2. For mottled seeds, average shoot masses of seedlings from scarified seeds also were significantly higher than for nonscarified seeds. Thus, vigorous seedlings were produced.

DISCUSSION

Many assumptions have been made concerning the capability of kudzu to grow in the northern United States. Sorrie and Perkins (1988) suggested that above-ground die-back may be important in preventing the spread of this taxon in New England. Flint (1983) also suggested that vines of this species were killed back by cold winter temperatures in Illinois, Indiana, Ohio and Pennsylvania. Our observations indicate, however, that kudzu vines do not die-back every winter in Illinois as stems with as many as 7 growth rings were found.

Fernald (1950), Sinclair et al. (1987) and Sorrie and Perkins (1988) stated that kudzu plants rarely produce fruits and viable seeds in the northern part of the United States. During the present study, fruits with seeds were found in six populations from central and southern Illinois (Table 2). Only small quantities of seeds (<60 seeds) were found in five of these populations, but a population at the Union County Fish and Wildlife Area produced large quantities (4500 seeds) with a high percentage of them viable (Table 4).

Most Illinois populations of kudzu were planted intentionally or became established with vegetative tissues as a result of human activities, such as being transported by construction and mowing equipment. Kudzu stems commonly root at the nodes when touching the ground, forming adventitous roots, and soon an elongated fleshy root (Miller and Edwards, 1983). These stems can be transported easily by construction equipment, and once buried, can continue to grow.

During the present study, seed germination and seedling establishment were highest with scarified/mottled seeds (Tables 4 and 5). The two seed coat colors observed during the present study (mottled vs. uniform) were not discussed by previous authors. These differences may be the result of early cessation of development with the mottled seeds having completed development before the fruits were killed by frost. The uniform seeds were smaller, and may have been immature, i.e., not fully developed. Additional studies are needed to investigate this speculation. Other environmental variations during seed development also might have influenced the appearance and vigor of these seeds (Baskin and Baskin, 1998). The mottled seeds had a harder seed coat and were more difficult to scarify than uniform seeds. Kudzu seeds from Illinois germinated at a wide range of temperatures and responded well to mechanical scarification for breaking dormancy. These responses are similar to previous reports for other legumes (Baskin et al., 1998) and for kudzu from other locations (Tabor, 1949; Tsugawa et al., 1979; Baskin and Baskin, 1998; Susko et al., 1999). The range of temperatures where kudzu seed germinated, indicate that it has the potential to become a major plant pest at least throughout the southern half of Illinois where seed was produced.

This study shows that viable seeds capable of producing vigorous seedlings are produced in Illinois at least during some growing seasons. It is therefore possible that some kudzu populations in Illinois were established from local seed sources rather than from vegetative tissues. Presently kudzu is uncommon in Illinois but population sizes and numbers have increased slowly during the last 50 years. This continual increase, coupled with an effective seed dispersal agent, could result in a population explosion, particularly in southern Illinois. This species is not expected to achieve the same degree of invasiveness in Illinois as in the southern United States. However, if not controlled, it has the potential of becoming a local problem, causing concern for rural landowners.

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Table 1. Location of known kudzu populations in Illinois, habitat of occurrence, and total area by county (ha).

County	Total Sites	Habitat Type						Total Area (ha)
		Roadside	Open Field	Woods	Home Site	Stripmine	Water Edge	
Alexander	3	2	1	-	-	-	-	15.0
Crawford	1	-	-	1	-	-	-	0.3
Fayette	2	2	-	-	-	-	-	1.0
Fulton	2	-	1	-	-	1	-	6.0
Gallatin	1	1	-	-	-	-	-	2.5
Greene	1	-	-	1	-	-	-	1.0
Hardin	2	1	-	-	-	1	-	2.0
Jackson	8	5	1	1	1	-	-	17.0
Jefferson	3	3	-	-	-	-	-	1.8
Jersey	2	-	-	2	-	-	-	2.0
Johnson	3	3	-	-	-	-	-	1.0
Madison	3	1	2	-	-	-	-	2.5
Massac	1	-	-	-	-	1	-	1.0
Monroe	2	2	-	-	-	-	-	1.0
Peoria	1	1	-	-	-	-	-	0.3
Perry	1	-	1	-	-	-	-	1.5
Pike	1	-	-	1	-	-	-	2.0
Pope	5	1	1	1	2	-	-	22.0
Pulaski	2	2	-	-	-	-	-	6.0
Randolph	3	-	3	-	-	-	-	14.0
Rock Island	1	-	-	1	-	-	-	0.3
Saline	5	-	1	-	-	4	-	6.0
Schuyler	1	-	-	-	1	-	-	0.5
Shelby	1	-	-	-	-	-	1	0.5
St. Clair	2	-	1	-	-	1	-	1.0
Tazewell	1	-	-	1	-	-	-	1.0
Union	8	3	-	4	-	-	1	4.4
Williamson	12	4	-	-	-	7	1	13.0
Totals	78	31	12	13	4	15	3	126.6

Table 2. Means and standard deviations for kudzu fruit length, fruit width, and number of seeds/fruit for selected Illinois populations. Ranges are in parentheses. Percent of mottled seeds is based on the total of mottled plus uniform seeds.

Population	Fruit Length (mm)	Fruit Width (mm)	Seeds/Fruit	Percent Mottled Seeds
Central Illinois				
Fayette Co. near Laclede	54.2 ± 9.3 (42-83)	8.5 ± 0.4 (8.0-9.3)	0.8 ± 1.0 (0-4)	0
Jefferson Co. 3 km N of Harmon	52.6 ± 7.0 (39-69)	8.1 ± 0.4 (7.5-8.8)	1.8 ± 1.1 (0-4)	56
Jefferson Co. 1.5 km N of Harmon	51.2 ± 11.9 (34-80)	8.0 ± 0.6 (6.8-9.0)	2.3 ± 1.3 (1-6)	20
Southern Illinois				
Jackson Co. 8 km S of Murphysboro	55.3 ± 7.1 (41-69)	7.3 ± 0.5 (6.4-8.5)	0.9 ± 0.9 (0-3)	80
Union Co. Fish & Wildlife Area	79.0 ± 15.6 (52-104)	7.3 ± 0.5 (6.0-8.2)	4.7 ± 2.2 (1-9)	65
Union Co. State Nursery	48.8 ± 4.5 (44-60)	6.9 ± 0.5 (4.5-7.7)	0.1 ± 0.3 (0-1)	0

Table 3. Means and standard deviations for mass and volume of mottled and uniform kudzu seeds from fruits collected at the Union County Fish and Wildlife Area, southern Illinois.

Seed Type	Mass (g) for 25 seeds	Volume (ml) for 25 seeds
mottled	0.34 ± 0.01 a[a]	0.29 ± 0.02 a
uniform	0.21 ± 0.02 b	0.23 ± 0.06 a

[a] means within a column followed by different letters are significantly different at 5% level based upon ANOVA

Table 4. Means and standard deviations for germination percentages after 14 days of mottled and uniform kudzu seeds with and without scarification. Fruits were collected at Union County Fish and Wildlife Area, southern Illinois (50 seeds/test).

Seed Type	Scarified		Nonscarified		
20°C					
mottled	98 ± 4	a[a]	22 ± 18	a	*[b]
uniform	34 ± 17	b	14 ± 13	a	ns
25°C					
mottled	100 ± 0	a	20 ± 16	a	*
uniform	36 ± 11	b	24 ± 9	a	ns
30°C					
mottled	100 ± 0	a	32 ± 11	a	*
uniform	18 ± 24	b	10 ± 7	b	ns
35°C					
mottled	94 ± 5	a	16 ± 9	a	*
uniform	14 ± 17	b	10 ± 10	a	ns

[a] means within a temperature pair in a column followed by different letters are significantly different at 5% level based upon ANOVA

[b] means within a row are significantly different (*) or not significantly different (ns) at 5% level based upon ANOVA

Table 5. Means and standard deviations for seedling characteristics after one month of growth for mottled and uniform kudzu seeds with and without scarification. Seeds are from fruits collected at the Union County Fish and Wildlife Area, southern Illinois.

Seed Type	Scarified		Nonscarified		
Emergence (%)					
mottled	76 ± 19	a[a]	32 ± 8	a	*[b]
uniform	2 ± 4	b	8 ± 13	b	ns
Height (mm)					
mottled	13.9 ± 2.4	a	8.8 ± 1.5	a	*
uniform	1.8 ± 4.0	b	3.4 ± 4.6	b	ns
Number of Nodes					
mottled	7.1 ± 0.4	a	4.1 ± 1.1	a	*
uniform	1.0 ± 2.2	b	1.0 ± 2.2	b	ns
Leaf Area (cm^2)					
mottled	39.6 ± 4.9	a	5.1 ± 1.6	a	*
uniform	3.6 ± 8.2	b	0.5 ± 1.1	b	ns
Fresh Shoot Mass (g)					
mottled	0.80 ± 0.10	a	0.14 ± 0.03	a	*
uniform	0.07 ± 0.17	b	0.02 ± 0.04	b	ns
Dry Shoot Mass (g)					
mottled	0.108 ± 0.013	a	0.023 ± 0.009	a	*
uniform	0.012 ± 0.027	b	0.003 ± 0.006	b	ns

[a] means within a pair for a given measured parameter in a column followed by different letters are significantly different at 5% level based upon ANOVA

[b] means within a row are significantly different (*) or not significantly different (ns) at 5% level based upon ANOVA

Figure 1. Distribution of *Pueraria lobata* (Willd.) Ohwi in Illinois, USA.

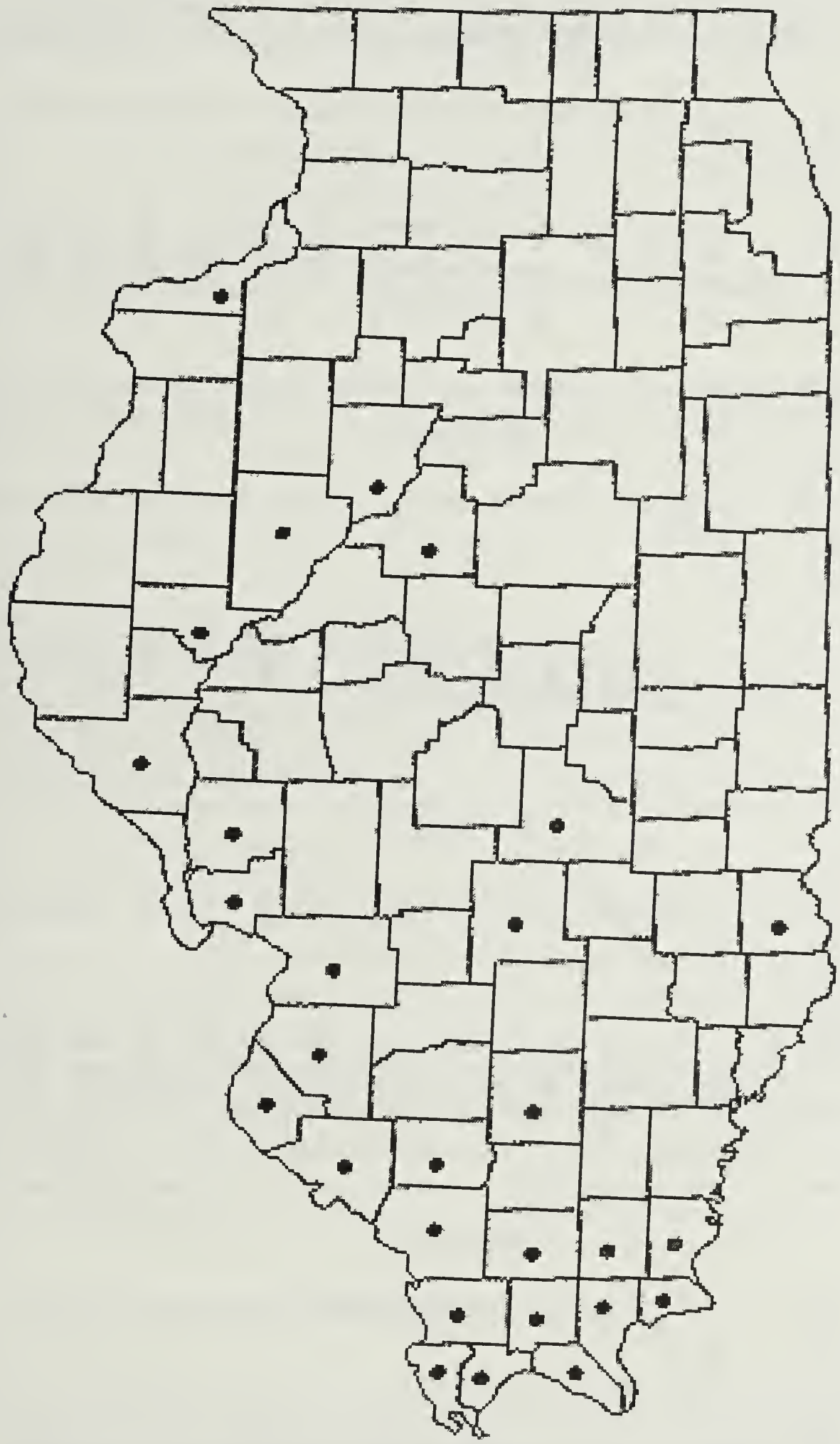
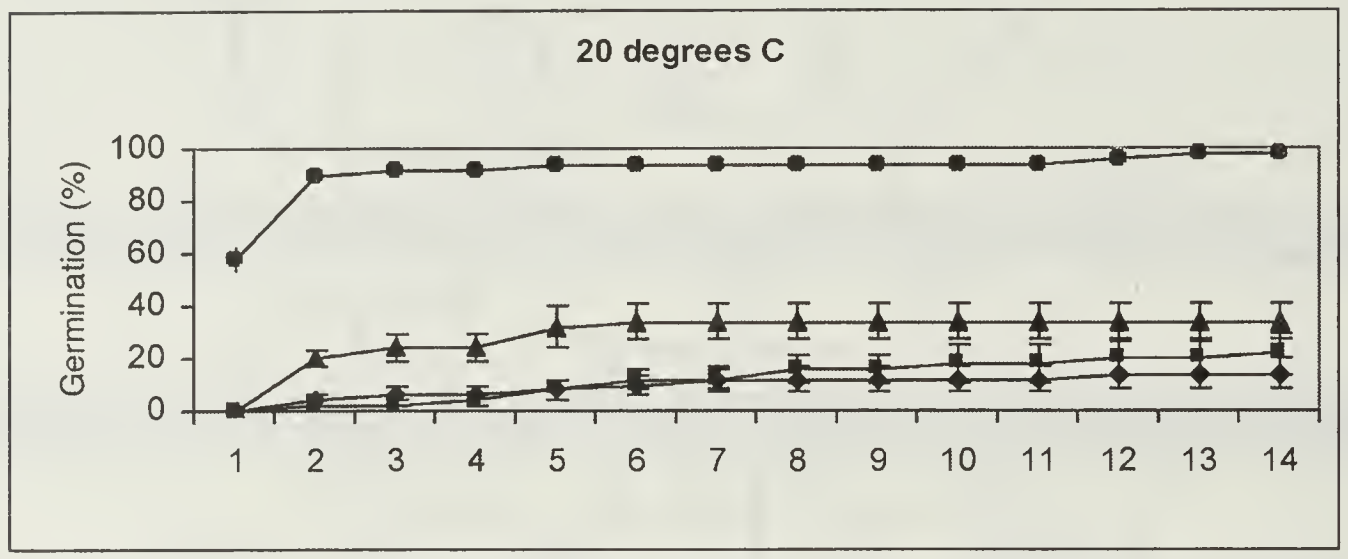
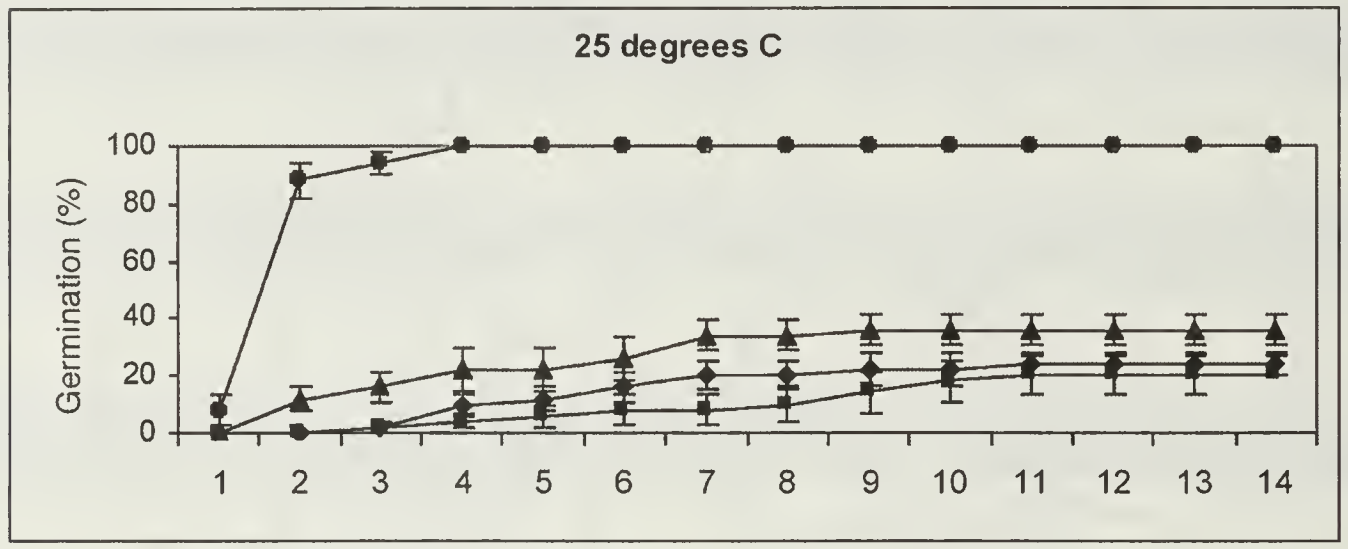
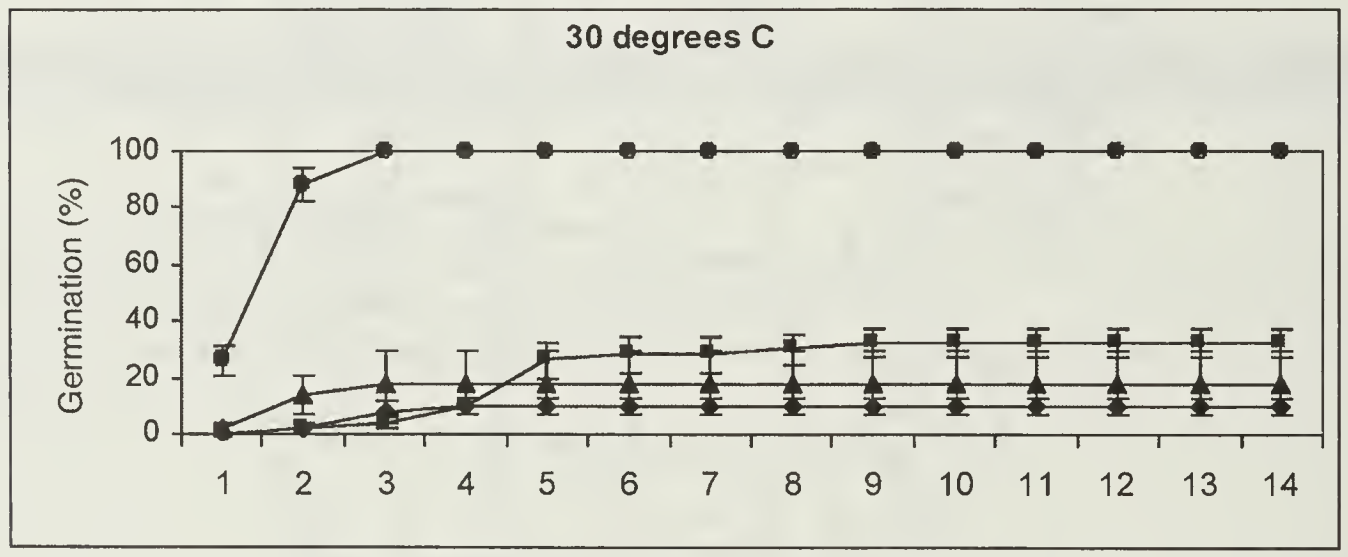
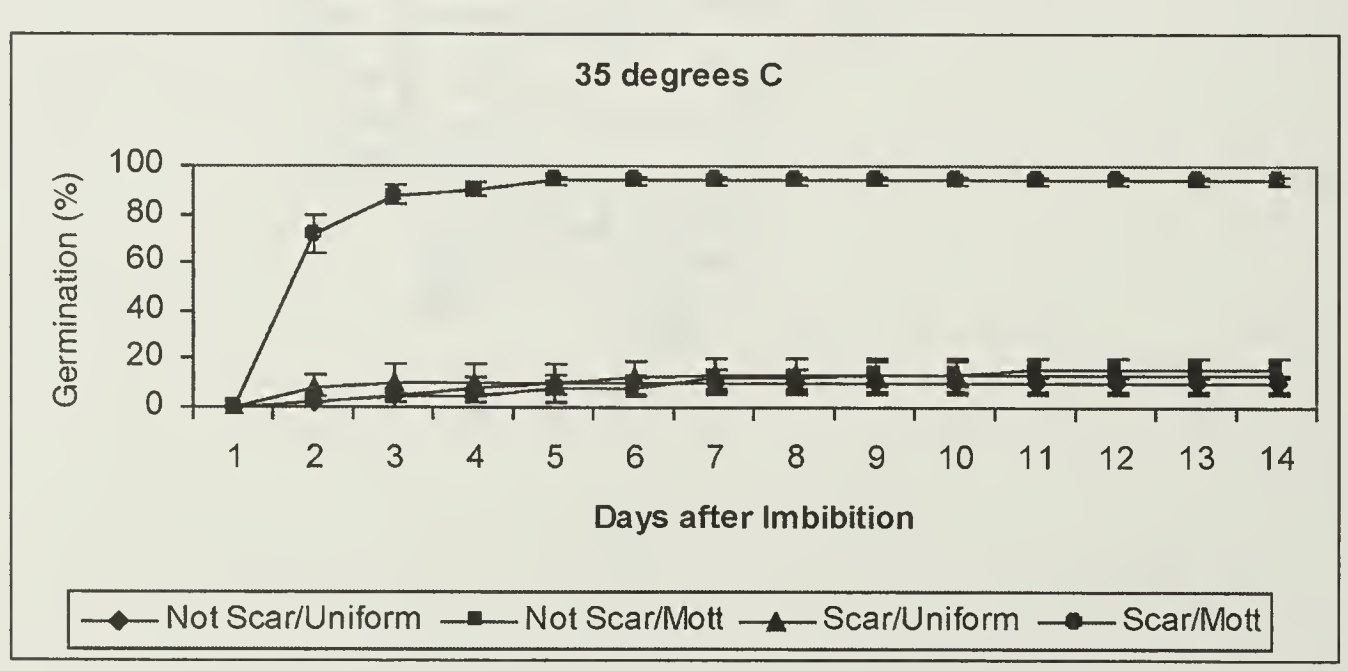


Figure 2. Means and standard deviations for percentage germination over time of mottled and uniform kudzu seeds with and without scarification. Fruits were collected at the Union County Fish and Wildlife Area, southern Illinois.









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Comparison of Common Factors Affecting Seed Yield in the Congeners, *Baptisi alba* and *Baptisia bracteata*

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ABSTRACT

This study examined the importance of floral display to pollination and ultimately the size of seed set of *Baptisia alba* (L.) Vent. and *B. bracteata* Muhl. ex Ell. (Fabaceae) as to provide evidence that competition for pollinators has influenced reproductive distinctions between the congeners. The congeners partially overlap in flowering period and share common pollinators. The *a priori* assumption was that if the congeners compete, the size of floral display would be a positive predictor of seed matured/plant. As both species are infested by the pre-dispersal seed predator, *Apion rostrum* Say (Coleoptera: Curculionidae) within the study site, the importance of seed predation as a conflicting variable to seed set of each congener was also studied. The study site was a 7.1 ha, 21-year old reconstructed tallgrass prairie located in northeastern Illinois. Individual *B. alba* produced more flowers, inflated pods, and seeds matured/flower than *B. bracteata*, but also had a higher mean count of *A. rostrum*/pod. Flower count/plant and *A. rostrum* count/pod were significant predictors of seeds matured/plant for *B. alba*, while only the former was a significant predictor of seeds matured/plant for *B. bracteata*. Differences in flowering period between the congeners should lessen competition for pollinators. Growth patterns may be adaptations linked to differences in the timing of flowering. The earlier springtime blooming period of *B. bracteata* when the prairie vegetation is emerging and pollinator activity is low, may select for showcasing floral display through a larger flower count/plant and clusters of plants. Height is not critical in the relatively barren landscape. Re-emergence of the prairie flora may select for greater height and multiple racemes in the later blooming period of *B. alba*, perhaps making *B. alba* to be more apparent to *A. rostrum*.

Illinois

INTRODUCTION

The white wild indigo (*Baptisia alba* [L.] Vent.) and the cream wild indigo (*Baptisia bracteata* Muhl. ex Ell.) are leguminous natives of mesic tallgrass prairie (Ladd 1995, Swink and Wilhelm 1994). Despite their close genetic relationship and the hosting of common pollinators, the congeners differ in stature, number of racemes per plant, and to some extent, flowering period (Haddock and Chaplin 1982). Such differences in morphology and reproductive patterns between flowering congeners have been argued to facilitate co-existence by reducing or eliminating the competitive advantage of one congener over the other (Brown et al. 2002).

In northeastern Illinois and the location of this study, *B. alba* and *B. bracteata* bloom during spring when pollinator activity is low (Pearson 1933). Bumblebees (*Bombus* spp.) pollinate both congeners which show overlap in flowering. *B. bracteata* blooms in May and into early June, while *B. alba* blooms from late May into the latter half of June. The much larger *B. alba* has abundant branches that commonly terminate in multiple smaller racemes in addition to a tall central raceme which can extend to 2m. The slender *B. bracteata* usually produces only a single arching raceme and grows to little more than 0.5m high. Both species have conspicuous flower displays. However, *B. alba* tends to form less densely populated clumps, with the multiple racemes of each plant projecting above the rejuvenating spring flora. In contrast, *B. bracteata* forms dense circular clumps of over a dozen individuals with racemes radiating outward (Petersen et al. 2000). The number of ovules per pod averages 35 for *B. alba* with most producing seeds, and 27 for *B. bracteata* with only slightly more than half initiating seeds (Haddock and Chaplin 1982). Pollination, subsequent pod and seed development, and maturation follow similar sequences in the congeners. Successful pollination is indicated by pod inflation (Haddock and Chaplin 1982). Pods ripen by early fall as the above-ground tissues senesce and seeds are released as the pods dehisce or fragment. The cycle of new above ground growth and reproduction commences with the return of spring.

Both *B. alba* and *B. bracteata* are infested by the pre-dispersal seed predator, *Apion rostrum* Say (Coleoptera: Curculionidae) (Petersen 1990, Petersen et al. 2000). Overwintering adult *A. rostrum* appear on plants beginning in late May and during the next month can be observed inserting eggs into inflated pods. Resulting offspring utilize seeds in the pod for their only source of nutrition. The weevils complete development inside the pods by August, dispersing as pods open. A major source of larval mortality is abortion of developing pods, particularly in *B. alba*, which results in the decay of the pods and the developing weevils within them (Petersen and Sleboda 1994, Petersen et al. 1998).

Our study examines the importance of floral display to pollination and ultimately the size of seed set of *B. alba* and *B. bracteata* for evidence that competition for pollinators has influenced the congeners. The *a priori* assumption was that if the congeners compete, the size of floral display would be a positive predictor of seeds matured per plant. We also study the role of seed predation by *A. rostrum* as a conflicting variable influencing seed set.

METHODS

The study was conducted in the 7.1 ha, Russell Kirt Tallgrass Prairie, a 21-year old 7.1 ha reconstruction located on the main campus of College of DuPage, DuPage County, Illinois. Prairie planting began in 1984. Over 150 species of native tallgrass forbs and graminoids, with big bluestem (*Andropogon gerardii* Vitman) and prairie dropseed (*Sporobolus heterolepis* Gray) being the dominant grass species in the prairie (Kirt, 1996) which is burned annually.

The study was conducted over one season of growth during 2004. Plants of *B. alba* and *B. bracteata* were randomly selected for study as they flowered during May and June. *Baptisia alba* and *B. bracteata* were monitored from flowering through seed maturation

and pod ripening to elucidate differences in and the importance of size of floral display to reproductive output. Flowers and pods that inflated were counted on each plant. During August and September as plants began to senesce, five sealed pods were collected from each raceme and sampled for counts of matured seeds and weevils. The most proximal, distal, and three pods spaced evenly between were those sampled. If a raceme had less than five pods, all pods were sampled. Seed yield was computed as the product of the mean count of matured seeds/pod and inflated pods/plant. The degree of weevil infestation was computed as the grand mean count of *A. rostrum*/pod among racemes of a plant.

Flower counts/plant, pods inflated/plant, seeds matured/plant, and *A. rostrum* counts/pod were compared between the congeners using one-way analysis of variance (ANOVA). The ratio of pods inflated/flower and seeds matured/flower provided measures of pollination success and reproductive reward, respectively, per flower produced. Counts of seeds/plant, pods inflated/plant, and weevils/pod were $\log_{10}(x+1)$ transformed prior to analysis to meet normality. The effects of flower count/plant and *A. rostrum* count/pod on $\log_{10}(x+1)$ transformed count of seeds matured/plant were evaluated for each congener using multiple regression. Redundancy of the two independent variables was examined with computations of correlation coefficient and tolerance (where 0 indicated redundancy and 1 independence). Significance was determined at $P \leq 0.05$. It was presumed that counts of seeds/plant and weevils/pod would not be collinear from evidence that *A. rostrum* evaluates individual pods as suitable oviposition sites (Petersen and Sleboda 1994). Curculionids are also known to chemically mark fruits as a deterrent to additional oviposition (Kozlowski et al. 1983). All statistical summarization and analyses were done using Statistica (Statsoft 2001).

RESULTS

Plants of *B. alba* produced more flowers ($F_{1,103} = 142.4$, $P < 0.001$), initiated more inflated pods ($F_{1,102} = 130.4$, $P < 0.001$), and had more seeds matured per plant ($F_{1,103} = 80.3$, $P < 0.001$) and flowers ($F_{1,103} = 24.1$, $P < 0.001$) than *B. bracteata* (Table 1). However, *B. alba* had a higher mean count of *A. rostrum* count/pod than *B. bracteata* ($F_{1,102} = 43.2$, $P < 0.001$). The ratio of pods inflated/flower did not differ significantly between the congeners ($F_{1,103} = 1.9$, $P = 0.167$).

Flower count/plant was a positive predictor of seeds matured/plant for both congeners, while *A. rostrum* count/pod was a negative predictor of seeds matured/plant only for *B. alba* (Table 2). Redundancy was not detected for the independent variables with either *B. alba* ($r = 0.021$, tolerance = 0.999, $N = 36$) or *B. bracteata* ($r = 0.052$, tolerance = 0.997, $N = 68$).

DISCUSSION

Flowering and growth patterns by *B. alba* and *B. bracteata* have sufficient selective value as evidenced by their persistence in the tallgrass environment. Moreover, the positive relationship between flower count/plant and seeds matured/plant indicates the importance of flower display to attracting pollinators, a competitive interaction that would be alleviated by the morphological and reproductive distinctions between *B. alba* and *B. bracteata*. The positive relationship between counts of flowers and seeds matured has also

been shown at the level of flower count/clump of *B. bracteata* (Petersen et al. 2000). A greater stature is not required by *B. bracteata* to attract pollinators when much of the surrounding floral landscape has just begun to reemerge. However, larger inflorescence size per individual as well as per cluster of *B. bracteata* appears to facilitate pollination without attracting higher counts of *A. rostrum*/pod. Clustering can also function to crowd out other plant species as to enable photosynthesis that is required to support the next season's reproductive effort (Harper 1977).

Flower initiation two weeks after that for *B. bracteata* in a rapidly emerging springtime community may select for a larger floral display among multiple racemes of a taller *B. alba*, again explaining the significance of flower count/plant to seeds matured. In addition, being taller and more profusely branched can provide *B. alba* the added leaf area to support photosynthetic needs. The cost of a greater stature of *B. alba* and/or later development than *B. bracteata*, appears to be a greater attraction and subsequent pod infestation by *A. rostrum* at the interspecific level. Where other factors such as nutrition or water stress may also affect seed yield (Brevedan and Egli 2003), increasing pod counts of the seed predator eventually should take a noticeable toll, explaining the significance of counts of *A. rostrum*/pod on seeds matured/pod.

Despite the non-significant difference in pods inflated/flower and the higher levels of pod infestation by *A. rostrum*, seeds matured/pod by *B. alba* was still 3.3 times greater, and seeds matured/plant 14 times greater, than for *B. bracteata*. Perhaps it is the higher number of seeds in pods in addition to the abundance of the pods on plants that draws more weevils to *B. alba*. Lower seed count/pod has been suggested to be an evolved response to counter seed predation in other legumes (Siemens et al. 1992), possibly explaining the lower seed counts/pod and the ratio of seeds initiated/pod ovules in *B. bracteata*. Conversely, *B. alba* may be more vulnerable to *A. rostrum* infestation due to having a later developmental period that more closely coincides to when the weevil is most actively ovipositing. Weevil selection of pods for oviposition, and oviposition activity, as well as the intensity of post-dispersal seed predation, seed viability, and seedling survival, have not been studied for either congener and would provide greater insight into the adaptive dynamics of the legumes in a tallgrass environment. The two congeners are also known to vary in alkaloid composition (Crammer and Turner 1967), a factor which may affect the probability of seed consumption.

The significance of flower display as a predictor of seeds matured/plant is evidence of the importance of inflorescence size to both *Baptisia* species. Interspecific competition for the spring population of *Bombus* may, in part, be reduced by the difference in the flowering times of the congeners. Varying selective pressures resulting from this difference, to include pre-dispersal seed predation by *A. rostrum*, may explain morphological and other reproductive distinctions between the congeners.

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Table 1. Sample mean ± sample standard error (sample size) of parameters of plant reproductive yield and pod infestation by *Apion rostrum* according to species of *Baptisia*.

Variable	Plant species	
	Baptisia alba	*Baptisia bracteata*
Flower count/plant	102.1 ± 10.3 (37)	17.4 ± 1.07 (68)
Inflated pod count/plant	54.1 ± 7.9 (37)	8.2 ± 0.8 (68)
Seeds matured count/plant	386.4 ± 66.2 (36)	27.9 ± 5.3 (68)
Inflated pod count/flower	0.73 ± 0.16 (37)	0.46 ± 0.03 (68)
Seeds matured/flower	5.05 ± 1.48 (36)	1.53 ± 0.25 (68)
Apion rostrum count/pod	1.47 ± 0.14 (36)	0.59 ± 0.06 (68)

Table 2. Summary of multiple regression analyses for counts of seeds matured/plant according to congener of *Baptisia* in relation to flower count/plant and *Apion rostrum* count/pod. Seeds matured/plant were $\log_{10}(x + 1)$ prior to each analysis.

	Whole model				Flower count/plant		*Apion rostrum* count/pod	
Species	P	F	r^2	N	P	t	P	t
Baptisia alba								
	<0.001	16.188	0.704	36	<0.001	4.318	<0.001	-3.797
Baptisia bracteata								
	0.006	5.527	0.145	68	0.003	3.121	0.196	-1.306

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Unexpected Impacts of Drought 2005 on Illinois Crop Yields: Are Weather-Crop Relationships Changing?

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ABSTRACT

Rainfall across Illinois was much below normal from March through July 2005, initiating a severe growing season drought. Temperatures from June through September were above normal adding to the potential stress on corn and soybean crops. During the summer, crop experts predicted major yield reductions, and crop quality surveys showed ever growing problems from June through August. However, the 2005 harvest produced statewide corn and soybean yields that were above average, and the soybean yield of 47 bu/acre was the state's second highest on record. This outcome, in contrast to the dire in-season predictions and crop surveys, raises important questions about the level of understanding about the relationship of weather and crop yields. Genetic improvements and better farming practices likely have altered how weather impacts crop yields.

INTRODUCTION

Large parts of Illinois suffered through a relatively severe drought during the 2005 growing season. The drought was characterized by deficient precipitation across much of the state, coupled with high summer temperatures. The chronology of the precipitation and temperature conditions from March through September 2005 and the reactions of various persons and institutions to the conditions are presented initially. Then the crop-related impacts resulting from this 7-month (March-September) drought period are presented. Political action began in late June to seek relief assistance for Illinois farmers, because the agricultural sector is an important part of the state's economy. However, the final crop yields were much higher than expected, ending efforts to get relief and raising serious questions about the in-season predictions of low yields and crop surveys that had indicated poor crop conditions.

THE DROUGHT AND REACTIONS

Statewide rainfall in March 2005 was 50 percent of average, being less than one inch in northern Illinois and three inches in deep southern Illinois (Fig. 1). The dry conditions were generally viewed as a blessing by farmers because they allowed early planting of corn. April rainfall continued the below normal trend (Fig. 1), being 1.1 inch below the statewide normal, and the statewide monthly temperature was much above normal (Fig.

2). Rainfall in May had an even greater departure below average, with a statewide average of 1.8 inches, which was 2.4 inches below the month's average and rated as the second driest May on record. The percent of average precipitation in each of Illinois' nine climate divisions fell below 65% for the month (Fig. 1). As a result, soil moisture from the surface down 20 inches at the end of May was well below average, being less than 75% of average across the state and less than 50% in parts of northern and central Illinois. The media began to carry stories about the emerging "drought" (Chicago Tribune, May 29), noting the drought was centered in Illinois and adjacent portions of surrounding states.

June conditions continued the dry regime with statewide rainfall being 1.8 inches below average (Fig. 1), and the statewide June temperature was 3.2°F above average (Illinois State Water Survey, July). Northern Illinois experienced the fifth warmest June since 1895 (Fig. 2). Near surface soil moisture amounts continued to fall in June with decreases of 20 to 70 percent across central and southern Illinois (Scott, July 7). At the deeper soil levels, 20 to 72 inches down, soil moisture continued to rapidly decline across the state, being less than half of the average across more than 50 percent of the state at the end of June. The emerging corn and soybean plants were using the soil moisture in the absence of adequate rainfall. Maps measuring existing droughts across the nation showed an area oriented southwest-northeast across Illinois and Missouri, and some portions in Illinois were classed as being an "extreme drought" (Farm Week, June 27).

In early June, crop experts and grain market experts began expressing concern over the developing agricultural drought in Illinois, and this was widely reported in the media (Farm Week, June 6, June 13). Atmospheric scientists reported on the drought's severity and compared it to the severe drought of 1988 (Farm Week, June 27). Concerns of farmers and agricultural interests in Illinois led the Governor of Illinois to assemble the state's Drought Task Force on June 26. They announced that the state's rainfall for March-June was the third lowest since 1895 and reported there was potential for severe agricultural impacts. Temperatures in June had been well above average adding to the crop stress. These warm and dry conditions were expected to severely impact the state's corn crop that had been planted early and was nearing its pollination stage which determines the crop's size and quality.

Farm leaders called for action and in mid-July urged the state to seek federal disaster assistance for Illinois farmers now expected to have poor crop yields in 2005. As a result, the quality of the crops in all 102 Illinois counties was assessed, and this effort found that within 101 counties more than 30 percent of the corn crop was in serious condition. The 30-percent level on one major crop is the level needed to qualify for federal aid. In late July the Governor of Illinois sent a formal request to the federal government (FEMA) for disaster assistance for 101 counties. (Farm Week, August 1a).

Conditions during July remained dry over half of the state (Fig. 1) and temperatures remained above average across the entire state (Fig. 2). Although rainfall in July, a critical time for corn, was well below average in the northwestern half of Illinois, the timely occurrence of rainfall from the passage of tropical storm Dennis on July 11-13 helped corn yields in the southern two-thirds of Illinois. A prior corn-weather study found that

rainfall in the 2-week period of June 29-July 12 enhanced corn yields more than rain at any other time (Changnon and Neill, 1968).

Crop experts agreed that corn and soybean crops were in worse shape than the yield estimates issued by the USDA in early July (Farm Week, July 18a), and the National Weather Service indicated that the July rains were insufficient to halt the drought (Farm Week, July 18b). Statewide crop surveys on July 25 reported that 55 percent of the state's corn crop was in poor to very poor condition (Farm Week, July 25). At the end of July, the average statewide rainfall was below normal. The March-July rainfall across the state was 8 inches below average and the number of days with temperatures of 90 degrees or higher varied across Illinois, being 8 to 20 days above average. National maps of drought impacts issued by the USDA in late August showed that the northwestern half of Illinois was experiencing extreme drought, the worst possible classification, and the rest of Illinois was in moderate drought (Fig. 3).

In a crop report issued in early August, the USDA predicted that corn yields in Illinois would be low, estimated at 125 bu/acre, as compared to an average of 142 bu/acre, and soybean yields were estimated at 39 bu/acre, 3 bushels less than average. Predicted corn yields in the Northwestern, Northeastern, Western, and Central crop districts were estimated to be much below average by 15 to 30 bushels. By early August crop experts reported that any future rain would not help the corn crop and might be of small aid to the bean yield (Farm Week, August 8a).

By the end of August, most experts believed the impacts of the on-going drought would be very serious for the Illinois corn crop, although soybean yield outcomes were seen as uncertain. (Drought Response Task Force, September 7). Crop surveys done in mid-August rated 61 percent of the Illinois corn crop as being poor to very poor, with 41 percent of the soybean crop in the same class (Farm Week, August 15). However, a late-August tropical storm brought considerable rainfall across the southeastern half of Illinois that was sufficient to bring August rain totals there above average (Fig. 1). A record number of tropical storms, a total of four, brought rain to many parts of Illinois between mid-June and mid-September, and the total rain from these storms was a significant contribution to the summer total rainfall (Fig. 4), ranging from 20 to 35 percent of all rains in the southeastern half of the state.

Farmers and crop experts began issuing reports in late August about wide differences in expected yields within fields, between fields, and between counties. Crop surveys done in many Illinois fields in late August found wide differences within many counties, and the lowest statewide corn yield found was 6.7 bu/acre and the highest was 203 bu/acre (Farm Week, August 29). Secretary of Agriculture Johanns came to Illinois in late August and inspected crops in northern Illinois, declaring them to be badly damaged by the drought and worthy of federal disaster aid (Farm Week, September 5).

Assessments of crop conditions made during the summer are shown in Table I. The quality of the state's corn crop dropped from 49% good in June to only 12% good by early August. Very poor corn was only 2% of the crop, as rated in early June, but this grew to 29% of the crop by early August. The status of the soybean crop also shifted dramati-

cally, from 55% rated as good or excellent in early June to only 19% good or excellent two months later.

Harvest began in September with hot and dry conditions persisting through the first three weeks of the month, helping the crops to dry down (Fig. 2). By September 15, 6% of the state's corn crop had been harvested and 8% of the bean crop. By September 18, 74 percent of the state's corn was mature (National Weather Service, September 20). Many farmers were expressing surprise at their yields with many being higher than expected. By October 23, 89 percent of the corn crop was harvested and 93 percent of the state's soybean crop. Interestingly, the USDA's yield estimates issued in early September called for higher yields, to 136 bu/acre for corn, an 11 bushel increase over their August estimate, and 41 bu/acre for soybeans. Many crop experts were surprised by these increases and questioned the USDA estimates (Farm Week, September 19).

The final statewide average corn yield was 143 bu/acre, which is 1 bushel above the 1994-2003 average but 37 bushels less than the record high yield of 2004. The statewide average soybean yield was 47 bu/acre, 5 bushels above average and the second highest soybean yield on record. The record high set in 2004 was 50 bu/acre. The prior severe drought in Illinois during 1988 produced a 42% reduction in Illinois corn yields and a 26% reduction in soybean yields (Riebsame et al., 1991).

The spatial distribution of the 2005 yields across Illinois revealed wide differences. Tables II and III present the corn and soybean yield values for the state's nine crop districts, showing that corn yields were above average in 5 of 9 districts, with yield averages greater than 10 bushels above average in the East, Southwest, and Southeast districts. The Northwest, Northeast, Western, and Central districts had below average yields, but the only sizable decrease was in the Northeast (14 bushels/acre). Soybean yields were above average in the state's nine crop districts, being more than 5 bushels above average in the East, East Southeast, Southwest, and Southeast. The harvested yields revealed those of both crops were much higher than had been expected in most of Illinois. The large difference between the low yields predicted during the summer and indicated in the crop surveys (Table I), and the final above average yields is a major question needing explanations. Some crop experts credited this surprising outcome to a variety of factors including the timeliness of the rains that did occur, better hybrids, and improved farm practices. Bioengineered corn varieties (e.g., biotech) developed very deep and complex root systems during 2005 and were found to produce yields 10- to 30-bushels per acre more than standard corn varieties (Farm Week, December 19). Research has shown that the continuing improvements in seed genetics and farming practices have led to an increase in corn yields at a rate of one percent per year (Troyer, 2000). This means a gain of 9 bu/acre over the past five years.

The dry conditions in May and June 2005 led corn plants to deep root and survive from the existing soil moisture. Fortunately, precipitation in the four months before March 2005 was much above normal, re-charging the soils at all depths with moisture sufficient to sustain corn growth. A second critical weather condition occurred on July 11-13 when rains from tropical storm Dennis fell over most of Illinois, when corn was in its yield critical pollination stage. This was in the 10-day period when prior research has shown rainfall to be most critical of the season for corn yields (Changnon and Neill, 1968). A

third timely weather event were rains in mid- to late-August. These supplied needed water to the soybean crop and helped result in high bean yields.

The drought produced mixed outcomes for crop diseases and insect pests that could have reduced yields. The dry conditions were considered favorable for the Japanese beetle population and aphids. The drought also left the corn crop vulnerable to the corn root-worm, and dry soils limited plant uptakes of pre-applied herbicides. However, the drought and lack of rain held off feared infestations of the Asian soybean rust (Farm Week, July 11) and many wheat diseases.

The drought did not hurt the state's winter wheat crop harvested in mid-summer as wheat yields averaged 64 bu/acre, just one bushel below the record set in 2004. The heat and dryness had detrimental effects on garden crops, and pumpkin yields were reduced (Farm Week, September 5). Orchard crops also were hurt by the heat, especially in areas where dry conditions prevailed. Peach yields were down 39% from those in 2004 (Illinois Agricultural Statistics Service, September 13). Drought conditions negatively impacted Christmas tree growers in two ways, causing brown patches to develop in existing trees and killing most recently planted trees and saplings. (Chicago Tribune, November 25) The drought also hurt hay and alfalfa crops, leading to a raise in prices for livestock feed (Farm Week, August 1b).

IMPACTS

The drought and its expected impacts on the state's major crops, corn and soybeans, had major effects on the grain market. At the end of May crop prices were rising as awareness of the emerging drought developed (Chicago Tribune, May 29). By early July a very volatile "weather market" had developed with prices fluctuating from day-to-day as the weather shifted from hot and dry to occasional rains (Chicago Tribune, July 5). However, as the summer wore on and the regional dimensions of the drought area became well-defined as being largely within parts of Illinois, prices began to fall during August. This resulted because crop yields in the other Corn Belt states were predicted to be high, and the USDA announced the national production of corn and soybeans would be high (Chicago Tribune, August 13).

Economic Impacts

Potentially poor yields in Illinois, but good yields elsewhere in the Corn Belt, spelled serious economic problems for Illinois farmers. They faced low yields and low crop prices. The flow of the Mississippi River was reduced sufficiently by August to affect barges carrying grain. Barge loadings had to be reduced, resulting in higher shipping costs (Champaign Gazette, August 11). Furthermore, other events were raising farm costs for energy and shipping. Hurricane Katrina did great damage on August 29 to grain elevators in the New Orleans area where 50% of all Illinois grain crops are handled for export, and the storm did immense damage to oil production facilities along the Gulf Coast. These two outcomes brought higher grain shipping costs and higher costs for fuel needed for grain drying and harvest. Experts reported that the 2005 crops were the most expensive ever (Farm Week, September 19) with average costs for corn at $206 per acre and $113 per acre for soybeans. Thus, experts predicted that the low yields, low prices, and higher costs would lead many Illinois farmers to store and not sell their crops.

What did the drought cost Illinois farmers? In mid-August the head of the Illinois Farm Bureau estimated that the loss to farmers would be $2 billion, as measured from their 2004 incomes when yields set all-time record highs (Farm Week, August 21). Loss estimates issued later were less, with crop experts claiming losses would be slightly more than $1 billion (Chicago Tribune, September 4). The U.S. Department of Agriculture announced on September 20 that the drought loss in Illinois would be $1.3 billion (Champaign Gazette, September 21).

Given low prices, the 2005 production of corn in Illinois (1.73 billion bushels) and of soybeans (425 million bushels) translated into farm income that totaled $5.626 billion for Illinois. This represented an average of $75,618 per farm. The 2005 total income to Illinois farmers was 31 percent less ($2.5 billion) than they received in 2004 when record high yields occurred. The 2005 total income was 5 percent ($266 million) less than the average for 1994-2003. Thus, the 2005 conditions cost Illinois farmers $34,000 in comparison to their 2004 income and was $3,570 less than the average farm income based on 1994-2003.

Without the rains from the four tropical storms that each affected large parts of the state (Fig. 4), crop losses would have been much higher. Farmers in the southern half of Illinois greatly benefited from these rains as corn and soybean yields were well above average (Tables II and III).

The drought 2005 impacts had various effects on future activities. One such impact was a lowering of farm land prices (Farm Week, August 8b). The drought also limited the uptake of nitrogen fertilizer in many fields, and this meant that less fertilizer would need to be applied in 2006. Some crop experts felt that the successful winter wheat yields in 2005 would likely lead to a greater planting of wheat in 2006. The lower income and tight economic conditions on many farms would lead to reduced purchases of farm equipment. Major seed firms reported no loss of seed corn supplies for 2006.

Government Actions

The issue of government assistance for Illinois farmers developed as the potentially serious impacts of the drought on Illinois crop yields became evident in June. In early July the Illinois Department of Agriculture began monitoring crop conditions in 51 counties for the development of a possible disaster declaration. To qualify for federal disaster assistance, a county has to have at least 30% production losses in one major crop. Farmers were advised to certify their crop acreage by July 15 to qualify themselves for inclusion in a disaster declaration or for federal crop insurance. In late June, the Governor activated the state's Drought Task Force, and it continued to meet during July and August to assess and report on the drought's status.

The Governor of Illinois decided in mid-July to request federal disaster assistance, and the federal Farm Service Agency (FSA) began assessing which counties were eligible. The FSA found that 101 counties qualified for disaster declarations, and the Governor formally requested federal aid in late July. The Illinois Treasurer also initiated a $100 million drought relief program to provide low interest farm loans. (Farm Week, August 1a). By the end of August, 700 loans had been made totaling $47 million. Approximately

65% of the Illinois corn and bean crops had been insured (Farm Week, August 15b). In late August 74,000 Illinois farms had projected drought-related crop losses greater than 30% (Farm Week, September 5).

Illinois' members of Congress all agreed they would push for federal aid for the drought, admitting that aid would be hard to obtain because the drought problem area was largely confined to one state–Illinois. To get the desired aid would likely require that Congress extend the 2003-2004 disaster assistance program legislation, slated to terminate on September 1, 2005. The advent of Hurricane Katrina with its huge losses along the Gulf Coast became an issue by September 1 that affected the potential for drought assistance to Illinois. As September wore on, Illinois' two senators pushed for a "drought relief plan" as a means for extending the 2003-2004 assistance legislation. Members of the House from Illinois offered three bills with different relief plans, revealing a need for a compromise. Political endeavors to get federal disaster funds for Illinois farmers went on hold during October and November. Some policy experts concluded that Congressional efforts to provide federal aid funds had ended when the above-average statewide corn and soybean yield values appeared in early October. However, in mid-December Congress was debating the dimensions of the $453 billion defense spending bill that included several non-defense items like farm relief and relief for Hurricane Katrina. The Senate had inserted $1.6 billion in the defense bill for farm relief resulting from droughts, floods, and hurricanes. However, the House refused to include the added farm relief funding, insisting that all relief funding ($29 billion) should go to victims of Hurricane Katrina (Chicago Tribune, December 21). Illinois' two senators argued against the House position, but were told that Illinois' key House members went along with President Bush's wishes which were against funds for farm relief. House members further claimed that the farm assistance efforts of the Illinois senators were a political ploy to try to thwart other provisions in the defense bill. Essentially, federal disaster relief for Illinois farmers had become an issue caught up in political differences in Congress.

Effects on Agribusinesses

The drought and its impacts on crops also had impacts on certain agribusinesses. For example, John Deere, a major producer of farm equipment, reported in August that sales had declined by 3.5% because of the drought and the company's stock values fell by 11%, leading the company to cut production (Chicago Tribune, August 17). In contrast, major seed companies and fertilizer firms reported no impacts from the Illinois-centered drought. The impacts of the drought, and fears of its continuation into 2006, led to major sales of biotech corn varieties that were found to be drought resistant in 2005. Two seed firms reported that their triple strain varieties were sold out by December 1, 2005 (Farm Week, December 19). The lower flow on the Mississippi River reduced barge loads and this was costly to farmers and barge companies. One barge firm reported having lost $300,000 due to smaller loads (Champaign Gazette, August 11).

The outcome for grain elevators was mixed with much grain assigned to storage. The high costs of crop production and shipping and low crop prices led many farmers to store their grain, a boost in income for some elevators. However, the inaccurate predictions of final yields created major crop storage problems at many elevators which partly occurred because many elevators had carried old corn during the summer, based on the predictions that the 2005 crop was going to be quite low. By late October, 97 million bushels of corn

were stored uncovered in piles on the ground (Farm Week, October 31) at considerable costs. Other factors affected the huge storage problem including the rapid harvest, high costs of grain shipping, and lack of barges and rail cars. Agricultural realtors were losers because the drought brought decreased land prices (Farm Week, August 8).

SUMMARY AND CONCLUSIONS

Agricultural experts all agreed, from early June until late August, that the crop impacts of the 2005 growing season drought in Illinois were going to be serious, with sizable reductions in crop yields. Unexpectedly, the final corn and soybean yields over most of the state were at or above average levels. Experts then speculated that the few rains that did occur were not heavy but timely, and further claimed that improved crop genetics and farm practices made the crops more resilient to drought. Regardless, these factors were not detected nor realized by agricultural experts during the growing season, suggesting that the crop-weather relationships in use do not adequately define current weather-yield relationships.

An important and interesting weather aspect of the growing season drought of 2005 was the rainfall, mainly in the southern third of the state, from the unusually frequent passages of four tropical storms. These storms produced no damages and sufficient rainfall to bring major benefits to those parts of Illinois which enjoyed above average crop yields.

Clearly the predicted low crop yields issued during the growing season and the much higher final yields reflect crop-weather relationships different from those established using data from earlier years. Past studies have shown that dryness and above average temperatures, as experienced in 2005, would have resulted in well below average yields (Changnon and Winstanley, 2000). Yet, in 2005, Illinois had above average corn and bean yields, and the state's soybean yield of 47 bu/acre was the second highest on record.

The 2005 yield outcome was the third consecutive year when estimated and final crop yields in Illinois have widely differed. In 2003 and 2004, higher-than-expected crop yields occurred as a result of copious sunshine that created positive yield effects that went undetected by experts (Changnon and Hollinger, 2004; Changnon and Changnon, 2005). Collectively, the incorrect in-season yield estimates of 2003, 2004, and 2005 suggest that crop genetics and farming practices have changed dramatically and have altered the stresses of weather. Crops are also more responsive to sunshine and crops are now capable of producing yields at higher levels than prior crop-weather studies have shown. The poor yield predictions in 2005 had serious impacts, including the government's extensive and fruitless efforts to get financial aid, and on grain elevators which suffered high costs for storing surplus grain unexpected from the yield forecasts.

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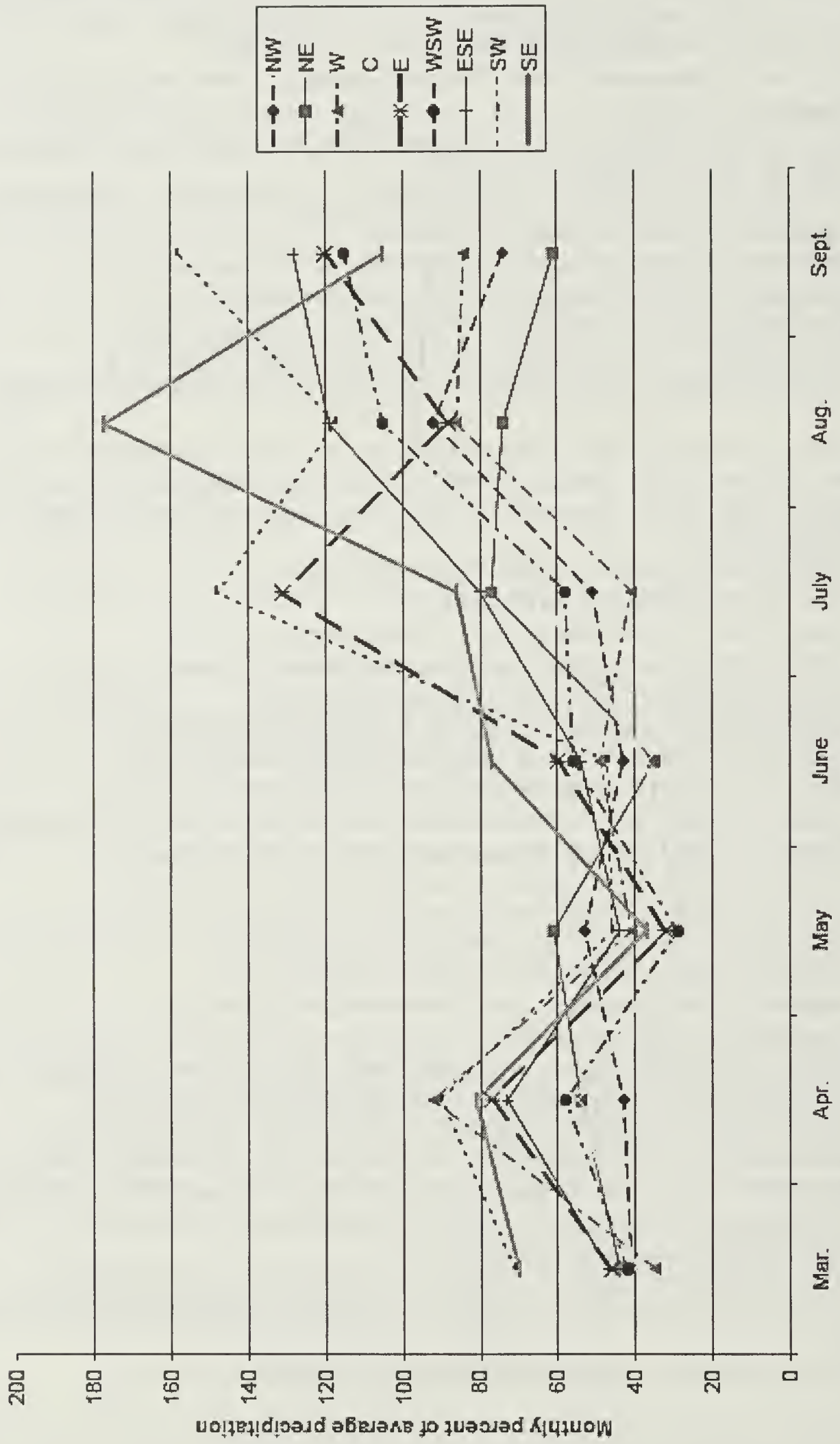

Figure 1. Monthly percent of average precipitation for each of Illinois' nine climate divisions, March-September 2005.

Figure 2. Monthly departure from average temperature (°F) for each of Illinois' nine climate divisions, March-September 2005.

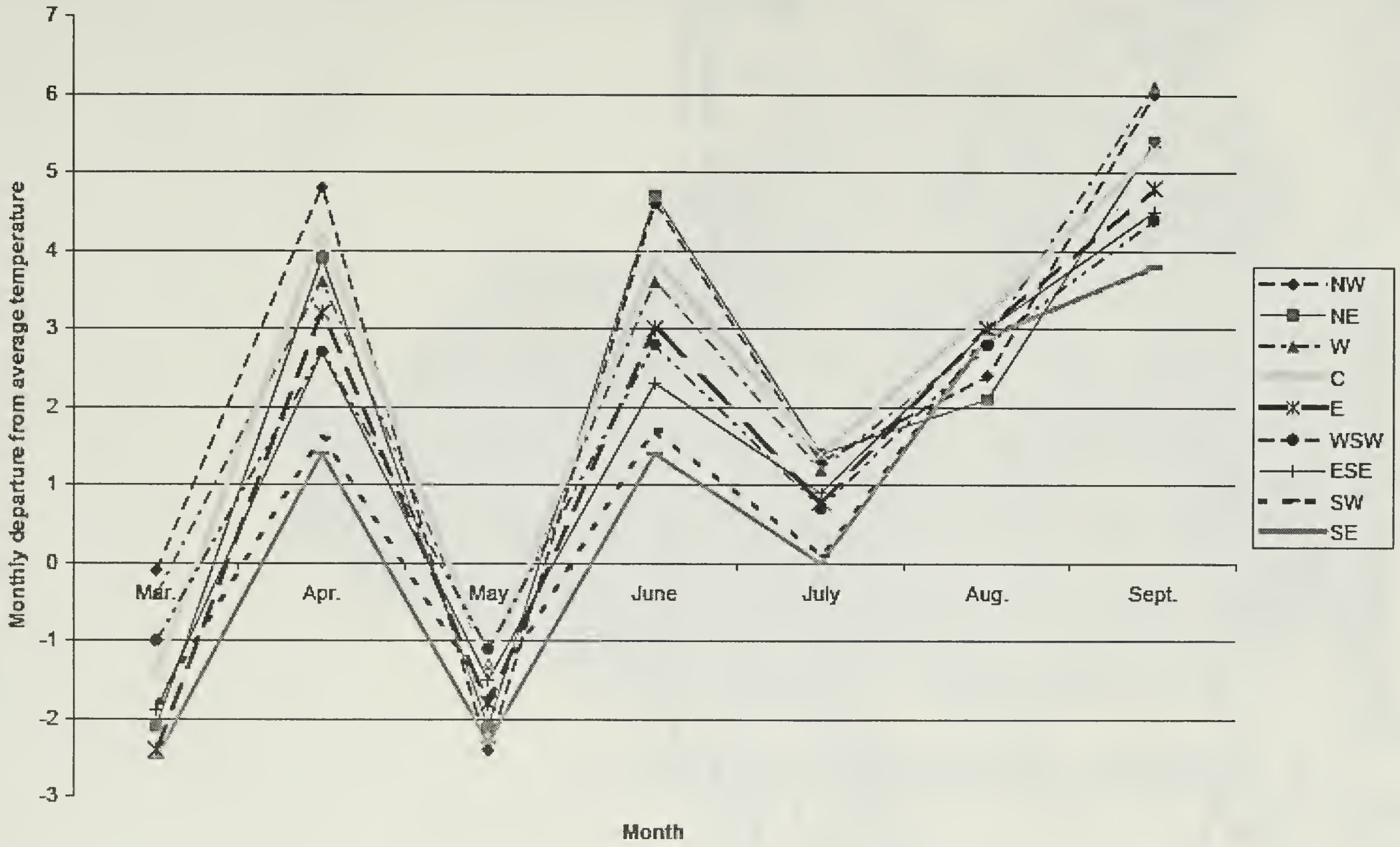

Figure 3. Drought conditions on August 23, 2005, as presented on the U.S. Drought Monitor (USDA).

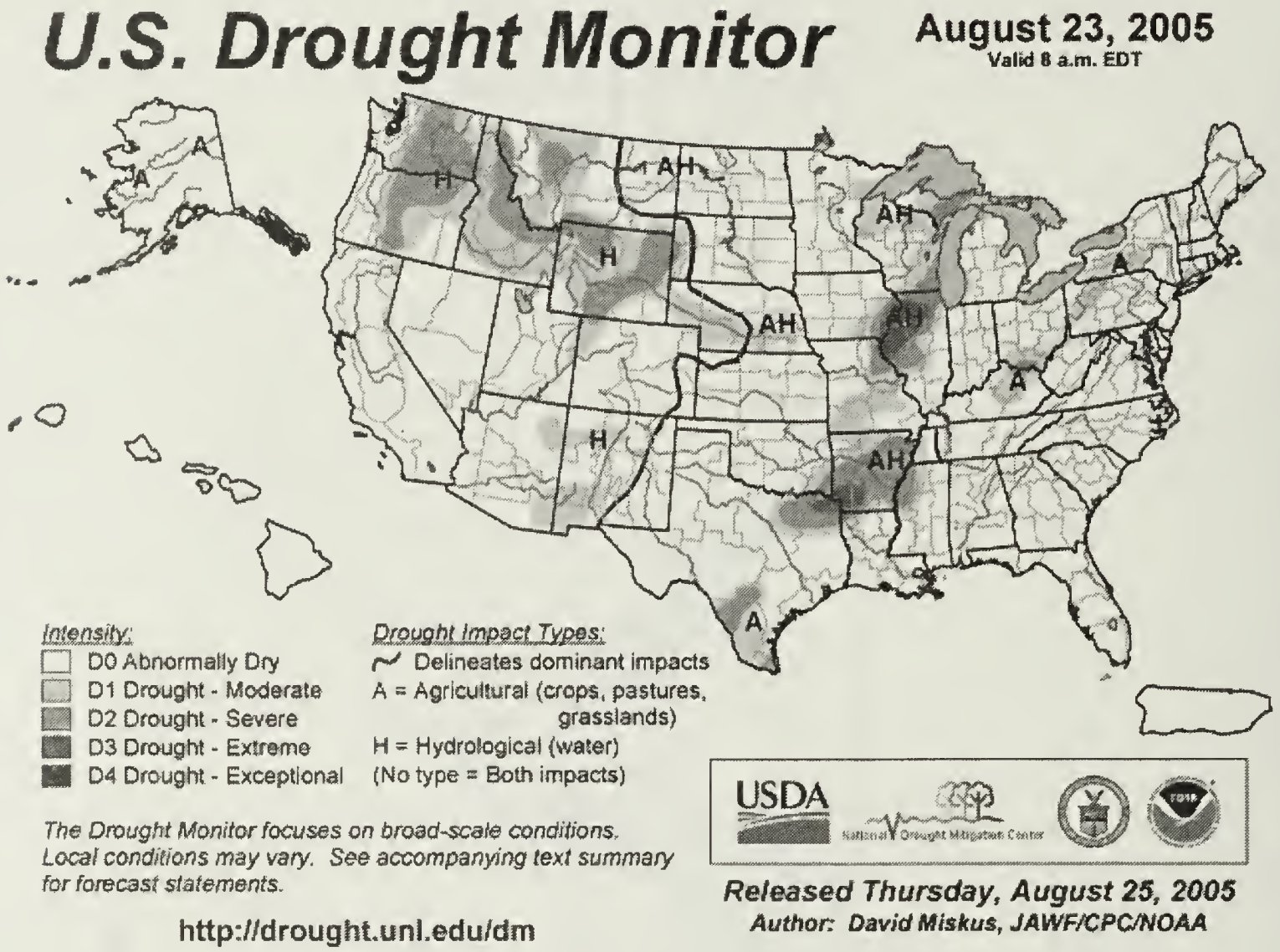

Figure 4. Rainfall for June-September 2005 derived from four tropical storms.

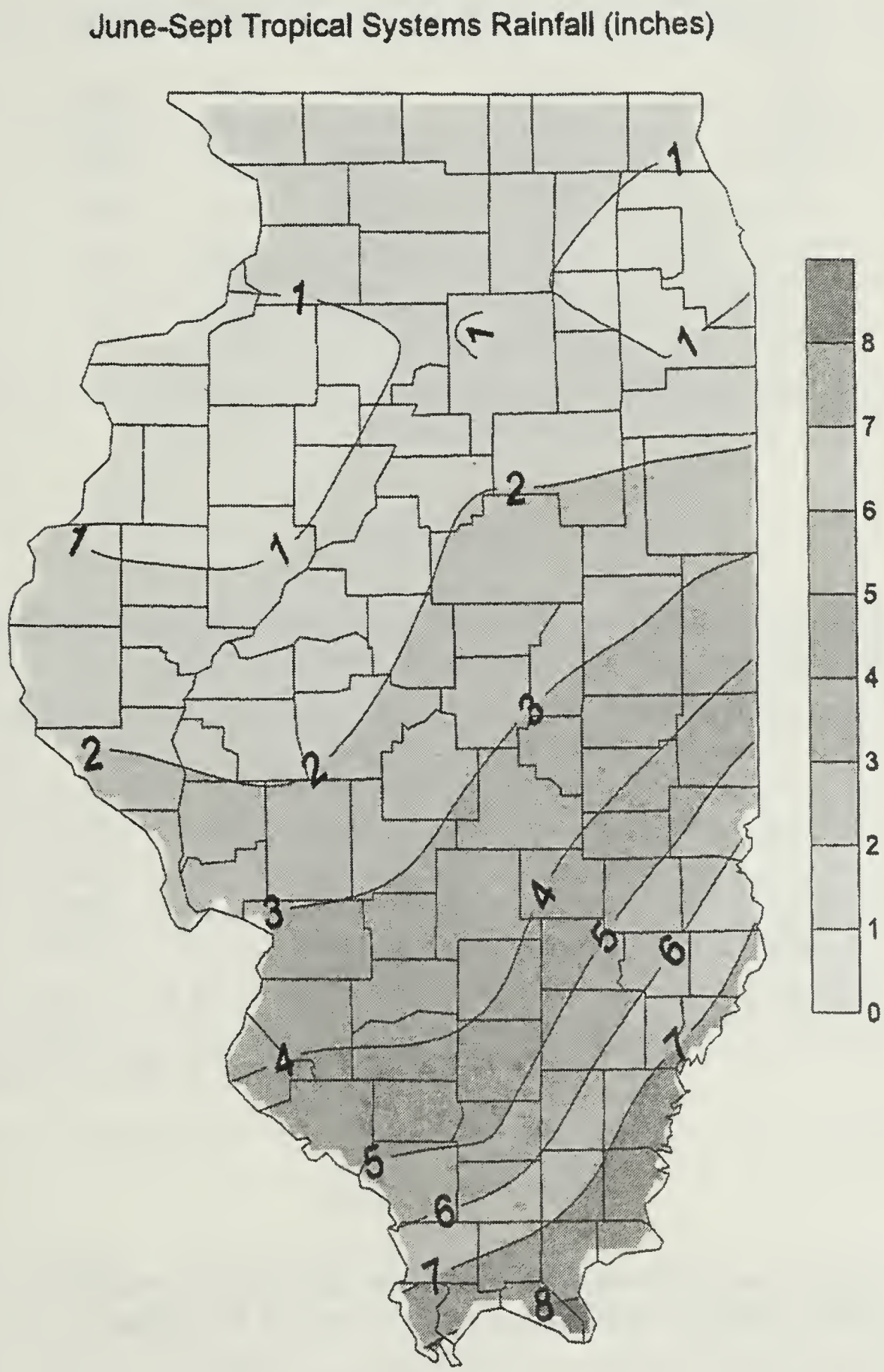

Table I. The status of Illinois corn and soybean crops during 2005. The amount of each crop in each category is expressed in percentages of the total crop in Illinois.

Crop	Date	Excellent	Good	Fair	Poor	Very Poor
Corn	June 5	6%	49%	34%	9%	2%
Corn	July 2	3%	29%	40%	20%	8%
Corn	August 7	0%	12%	27%	32%	29%
Soybeans	June 5	5%	50%	33%	10%	2%
Soybeans	July 2	2%	31%	43%	17%	7%
Soybeans	August 7	1%	18%	40%	25%	16%

Table II. Regional corn yields in Illinois for 2004, 2005, averages for 1994-2003, and the difference between the average and the 2005 value.

	Crop Districts								
	NW	NE	W	C	E	WSW	ESE	SW	SE
2005	140	129	141	146	158	151	139	133	130
2004	184	174	192	186	180	186	175	158	158
Average	149	143	149	154	144	147	130	110	110
Difference	-9	-14	-8	-8	+14	+4	+9	+23	+20

Table III. Regional soybean yields in Illinois for 2004, 2005, averages for 1994-2003, and the difference between the average and the 2005 value.

	Crop Districts								
	NW	NE	W	C	E	WSW	ESE	SW	SE
2005	48	44	47	51	51	46	46	42	44
2004	52	51	53	54	52	51	50	44	44
Average	46	43	46	47	45	43	39	34	34
Difference	+2	+1	+1	+4	+6	+3	+7	+8	+10

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Monitoring the Status of Mink (*Mustela vison*) in Illinois

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ABSTRACT

Methods to census mink (*Mustela vison*) at large spatial scales are lacking. Therefore, we used museum records, trapper questionnaires, and sign surveys to determine their distribution in Illinois. We also evaluated the potential for using museum records and sign surveys to detect trends in relative abundance. From 1999 to 2005, biologists detected the presence of mink during 326 visits to 77 stations in 74 counties. Curators of 6 collections provided information about 166 specimens from 35 counties. Few (n = 17) were recent (1980-2004) records. A total of 293 trappers reported capturing 1,321 mink during the 2003-04 and 2004-05 trapping seasons. Altogether, we documented recent occurrences of mink in 92 of 102 counties. Harvest estimates and questionnaires are adequate for monitoring the status of mink; museum records are not. Sign surveys can be implemented at a cost of <$14,000 (US) annually to derive quantitative estimates of relative abundance from site occupancy data if status becomes a concern.

INTRODUCTION

Quantitative methods to determine absolute or relative abundance of mink (*Mustela vison*) at a large spatial scale are lacking (Eagle and Whitman 1987). Therefore, status assessments consist of expert opinion supported by data from harvest records (Forbes 1912, Soper and Payne 1997), museum voucher specimens (Hoffmeister 1989), and questionnaires returned by fur-takers (Mohr 1943), government officials (Wildhagen 1956, Bevanger and Ålbu 1986) or other authorities (Gerell 1967, Bevanger and Henriksen 1995). Such assessments are adequate for immediate conservation needs (Larivière 2003) but lack rigor required for direct comparisons at a later time.

We documented the current distribution of mink in Illinois to determine whether changes have occurred since Hoffmeister's (1989) assessment. Our sources of data included museum records and sign surveys. We evaluated suitability of these data for applying analytical innovations that allow detection of trends in relative abundance. We also pro-

vide costs for determining site occupancy so managers can decide if adequate resources are available to do so.

METHODS

Sign Surveys

Trained staff from the Illinois Department of Natural Resources (IDNR) conducted sign surveys at a sample of Basin Survey Sites established by the Illinois Environmental Protection Agency (1996) and IDNR to monitor surface water quality, diversity and abundance of fishes, and other indicators of the biotic integrity of riverine systems. We selected 75 of 102 counties for sampling based on the existence of Basin Survey Sites, delineations of watersheds [≤3 stations per population management unit as defined by Bluett et al. (1995)], and assigned work areas (typically, each biologist sampled 2 counties).

Practical considerations limited strict random selection of sites within counties. Sites that might have been difficult to locate or access (e.g., in the center of a large river with no corresponding landmarks on shore) were not considered. Those that were part of the Ambient Water Quality Monitoring Network (AWQM) were given preference. For example, if a county had 10 stations, 2 of which were part of the AWQM, we listed the 2 AWQM stations in random order followed by 2 standard Basin Survey Sites in random order. If no AWQM stations occurred in a county, 4 standard Basin Survey Sites were listed in random order.

We do not believe that our sampling strategy biased results because AWQM stations are considered representative of the stream reaches where they are located (Illinois Environmental Protection Agency 2002) and differ from standard Basin Survey Sites primarily because a greater number of chemical, physical, and biological characteristics are assessed at AWQM stations than standard Basin Survey Sites. Biologists evaluated sites in the order listed, selecting the first with conditions deemed suitable for detecting the presence of mink (e.g., waterways with rock or sod-bound shorelines were rejected). With a few exceptions, sites selected the first year were sampled during subsequent years.

Biologists conducted sign surveys once per year during 1 Feb through 31 Mar in the southern furbearer zone (i.e., south of U.S. Route 36) and 15 Feb through 15 Apr in the northern zone. Snow cover was not a prerequisite for conducting surveys and seldom existed during sampling. We avoided sampling shortly (<48 hrs) after rainfall that might obscure or eliminate sign and while rivers were rising quickly or at flood stage.

Using hip chains to determine distances, biologists traveled ≤300 m upstream and downstream from survey mid-points (i.e., road bridges identified as Basin Survey Sites or AWQM stations), and searched both shorelines for tracks, scats, and other signs of the presence of mink, river otter (*Lontra canadensis*), and beaver (*Castor canadensis*; i.e., a total of 1200 m of shoreline unless the presence of all 3 species was documented in a shorter distance). Data collected by staff included the presence of target species and types of evidence encountered. They also reported the percentage of shoreline with conditions deemed suitable to detect an animal's presence. Suitable conditions consisted of a band of sand or mud substrate along the water's edge; width of the band varied from a few centi-

meters to approximately 2 meters from the water's edge depending on substrate, slope, presence of rank vegetation, and other attributes of the bank. We calculated detection rates by dividing the number of sites where mink were detected by the total number of sites sampled.

Costs, tracked by IDNR's Programmatic Accounting System for reimbursement under Federal Aid in Wildlife Restoration Project W-99-R, were based on man-hours coded to the project for all tasks (i.e., data collection, entry, and analyses; preparation of reports), included an indirect cost of 23.3%, and are reported in US dollars.

Museum Specimens

Hafner et al. (1997) identified mammal collections in the Western Hemisphere. Using this guide, we sent letters to curators of large collections (>500 specimens) located in Illinois to obtain information about dates and locations that mink were collected. An initial request was mailed during December 2004; non-respondents received a second request during October 2005. We also searched 7 on-line databases (Burke Museum of Natural History and Culture, Yale Peabody Museum, Florida Museum of Natural History, University of Massachusetts at Amherst Mammalogy Collection, University of Alaska Museum of the North, Harvard University Museum of Comparative Zoology, and University of California, Berkeley Museum of Vertebrate Zoology) for information about specimens housed at out-of-state institutions. We judged the relative value of our sample by comparing sizes of collections housed by respondents and on-line sources to collections documented by Hafner et al. (1997).

Trapper Questionnaires

Each year, the Illinois Natural History Survey sends questionnaires to a stratified random sample of licensed trappers to determine their harvest, harvest effort, and opinions about management programs. Most (78%) of the 665 trappers contacted after the 2003-04 season responded (Miller et al. 2004), as did most (79% of 684) contacted after the 2004-05 season (Hubert et al. 2005). Respondents comprised approximately 18% of all licensed trappers during the 2003-04 season and 17% during 2004-05 (Miller et al. 2004, Hubert et al. 2005). More detailed methods and summaries were described in unpublished reports to IDNR (Miller et al. 2004, Hubert et al. 2005). We used raw data to link captures by successful mink trappers to the inquiry, "In which county did you do most of your trapping?"

RESULTS

Sign Surveys

Biologists made 454 visits to 78 stations in 75 counties during 1999 through 2005. They detected mink during 326 visits (71.8%) to 77 stations in 74 counties during this period (Fig. 1). Mink were detected frequently (≤67% of visits) at 49 stations and infrequently (≤33% of visits) at 12 (Appendix I). Detection rates varied from 0.69 to 0.73 during 2000 through 2004, when 70-75 stations were visited annually. The greatest detection rate (0.85) occurred in 1999 when 41 stations were sampled; the least (0.64) occurred in 2005 ($n = 47$).

Costs were similar in 2003 (235.5 man-hours; $10,218.55; 73 survey locations) and 2004 (231.5 man-hours; $10,723.25; 70 survey locations). Scaled-back efforts in 2005 (47 survey locations) cost $7,388.10 for 164 man-hours. During 2003 through 2005, the average cost per survey location per year was 3.32 man-hours valued at $149.10, including indirect costs.

Museum Specimens

Curators of 6 collections in Illinois (Field Museum of Natural History, Illinois Natural History Survey, Illinois State Museum, Illinois State University, Southern Illinois University at Carbondale, and University of Illinois Museum of Natural History) provided information about 166 specimens of mink with associated dates and/or locations of collection. Our on-line search yielded information about 2 additional specimens. Based on a recent assessment of mammal collections (Hafner et al. 1997), institutions in our sample housed approximately 96% of specimens kept in Illinois and 19% of those in North America.

Locations were available for 146 specimens from 35 counties. Dates were available for 145 specimens; the most recent was collected in 2002. Seventeen specimens were collected during 1980-2004, 71 during 1955-1979, 36 during 1930-1954, 17 during 1905-1929, and 4 during 1899-1904. Runs of years (≤2) without collections were more common from 1980-2004 (n = 6) than 1955-1979 (n = 1), 1930-1954 (n = 2), and 1905-1929 (n = 2). The longest run (16 yrs) occurred from 1909-1924.

Trapper Questionnaires

Questionnaires distributed after the 2003-2004 trapping season resulted in 517 usable responses from trappers residing in 85 of 102 counties; these included responses from 140 successful mink trappers who reportedly captured 695 mink. Questionnaires distributed after the 2004-2005 season resulted in 535 useable responses from trappers residing in 77 counties; these included responses from 153 successful mink trappers who captured 626 mink. Data from both years suggested captures occurred in 74 of 93 counties where respondents (including those who did not capture mink) did most of their trapping. Reports for most of the 74 counties included responses from multiple successful mink trappers (58 counties) during multiple years (36 counties) and were confirmed by detection of mink during sign surveys (56 counties).

DISCUSSION

Our findings indicated a statewide distribution of mink. This result is not surprising given past assessments in Illinois (Forbes 1912, Mohr 1943, Hoffmeister 1989) and the species' widespread range elsewhere in North America (Larivière 1999). However, our work provides a more contemporary and complete reference than Hoffmeister (1989), who documented 62 museum specimens and 2 published reports from 24 counties. It also provides an opportunity to examine the relative value of available sources of data. For example, lack of recent (1980-2004) museum specimens limited usefulness of these data for determining distribution. Questionnaires provided results similar to but less precise and accurate than sign surveys. If necessary, we could obtain more detailed information about locations by modifying the survey instrument, as was the case for long-tailed weasels (*Mustela frenata*) in Illinois (Richter 2005).

Mink, considered common to abundant in most of their range (Larivière 2003), are harvested legally in nearly all states and provinces where they occur (Novak et al. 1987). Managers often rely on harvest records to infer status because direct methods to census or monitor populations at large spatial scales are lacking (Ray 2000, Larivière 2003). The secure status of mink suggests this approach is adequate (Larivière 2003). However, other methods are desirable (Linscombe et al. 1982, Ray 2000, Larivière 2003) because changes in capture effort caused by varying pelt values (Clark et al. 1985), numbers of trappers, and other factors (Bluett 1992) sometimes mask underlying relationships between population and harvest levels (Erickson and Sampson 1978, Erickson 1981).

Various forms of sign surveys (e.g., track-boards, sand-transects, searches of natural substrates along shorelines) have been used to monitor occurrence, habitat use, and activity of mink at relatively small spatial scales such as a site or watershed (e.g., Burgess and Bider 1980, Humphrey and Zinn 1982, Mason and MacDonald 1983, Loukmas and Halbrook 2001). Our use of this method to determine distribution at a statewide scale is the first we are aware of. We observed high detection rates with little variation among years when we conducted sign surveys at >70 sites. These characteristics suggest sign surveys would have been well suited for calculating trend and possibly relative abundance if we had used multiple sampling to estimate detection error, a requisite for applying recent innovations for analyses of presence-absence data (e.g., Strayer 1999, Royle and Nichols 2003, MacKenzie 2005, Stanley and Royle 2005). We believe this approach would be useful in jurisdictions where the status of mink is a concern.

Costs are an important consideration for resource managers seeking to implement monitoring programs (Field et al. 2005). Based on our experience, sampling 70 sites annually would cost 232.4 man-hours valued at $10,437, including indirect costs. Re-sampling one-third of these sites each spring to estimate detection error would add 77 man-hours valued at $3,429. These costs are greater than those for detecting only mink (i.e., our protocol required biologists to sample a total of 1200 m of shoreline unless the presence of mink, river otter, and beaver was documented in a shorter distance). Detection rates for river otter (26.8–35.7%; Bluett et al. 2004) were lower than those for mink. Therefore, the maximum distance was sampled at most sites. Distance or time elapsed from the beginning of the survey route until evidence of mink is first encountered might be useful metrics that would incur few if any additional costs (E.C. Hellgren, Cooperative Wildlife Research Laboratory at Southern Illinois University, personal communication).

Fewer sites were sampled during 1999, when sign surveys were initiated in southern Illinois, and 2005, when they were phased-out by eliminating sites where evidence of river otters had been observed ≤3 times. Detection rates observed during 1999 and 2005 were not anomalous, per se, but it seems improbable that the greatest and least values occurred during these years by chance alone. Possible explanations include differences among observers, sample sizes, populations, site characteristics, or a combination of factors. Our experience supports the notion that design is an important consideration for monitoring wildlife at large geographic scales (Pollock et al. 2002, Stanley and Royle 2005) and suggests some approaches might be less effective than others for monitoring mink, especially if the number of sites sampled annually is small (e.g., <70).

Several researchers have developed statistical approaches for inferring threat or decline from museum records (e.g., Solow 1993, Burgman et al. 1995, McCarthy 1998). In general, these methods assume a relationship between relative abundance and accessions, are most meaningful when used with information from other sources, and are best suited for comparisons within taxa or other aggregations of species (Burgman et al. 1995). Some approaches assume that collection effort is relatively constant over time; others allow for differences that might occur because of changes in policies, funding levels, restrictions, or other abiotic influences on numbers of accessions of a particular species (McCarthy 1998).

We do not advocate use of these methods for monitoring the status of mink in Illinois because collection records do not appear to reflect relative abundance. For example, the number of collection records we documented from 1980–2004 (n = 17) was small compared to the estimated harvest of mink by trappers during that period (n = 199,966; Illinois Department of Natural Resources, unpublished data). Museums' efforts to collect mink probably declined during 1980-2004, as evidenced by more runs of absences and fewer specimens than the quarter-century preceding this period. The total number of mammal specimens housed by respondents increased approximately 21% from 1983-1995 (Yates et al. 1987, Hafner et al. 1997), indicating that collection of mink deviated from this trend.

The mink's status appears secure in Illinois. Given limited resources, we believe harvest records and trapper questionnaires provide adequate monitoring tools. If these sources of data indicate cause for concern, sign surveys, which were discontinued in 2006, could be re-instituted with multiple sampling efforts at a subset of locations to estimate detection error, trend, and relative abundance. Our data provide a baseline for future comparisons of the distribution of mink in Illinois and possibly a means of identifying underlying causes of decline linked to water quality, abundance of prey, or other metrics associated with Basin Survey Sites.

ACKNOWLEDGMENTS

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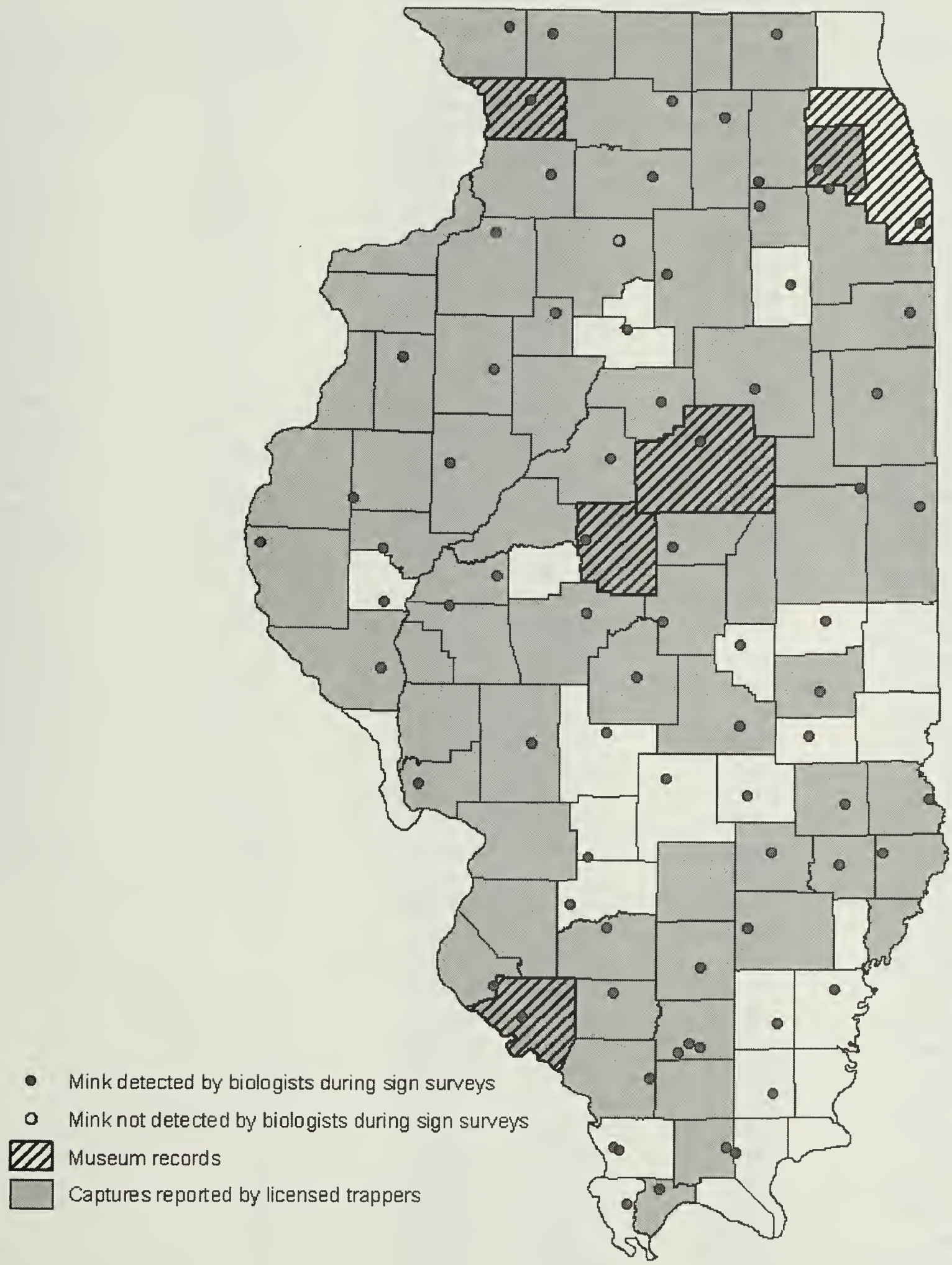
Figure 1. Distribution of mink in Illinois from recent sign surveys (1999-2005), museum records (1980-2004) and captures reported by random samples of licensed trappers (2003-2005).


Mink detected by biologists during sign surveys
Mink not detected by biologists during sign surveys
Museum records
Captures reported by licensed trappers

Appendix I. Basin Survey Sites where biologists searched for evidence of mink (*Mustela vison*) in Illinois, 1999-2005.

County	Identification code for Basin Survey Site	Location (decimal degree)		No. years surveyed	No. years mink detected
Adams	KI04	40.12685	-91.41717	6	4
Alexander	IXD01	37.21490	-89.30025	7	4
Bond	OIC02	38.75368	-89.52894	7	7
Brown	DE03	39.87834	-90.70076	7	7
Bureau	DQ05	41.48644	-89.36876	5	0
Carroll	NONE	42.10000	-89.89000	6	4
Cass	EEA01	39.99824	-90.05745	4	2
Champaign	BPK13	40.38508	-87.96425	6	5
Christian	EOH01	39.55256	-89.25351	5	5
Clay	C19	38.77568	-88.49086	7	3
Clinton	OH01	38.54148	-89.62663	6	3
Coles	BENC01	39.48776	-88.20940	7	6
Cook	HBDA01	41.55686	-87.59577	5	1
Crawford	BF01	39.00460	-87.59748	7	6
Cumberland	BEJH01	39.28721	-88.27617	6	6
DeKalb	PQC05	42.02802	-88.73879	3	3
DeWitt	EIH01	40.12950	-89.04760	6	6
Douglas	BE14	39.79973	-88.17041	7	1
DuPage	GBK12	41.79593	-88.18713	6	6
Effingham	C28	39.02838	-88.62317	7	2
Fayette	OO01	39.10201	-89.08863	7	5
Franklin	NH26	37.92798	-88.96067	3	1
Franklin	N11	37.89145	-89.01973	2	1
Franklin	NHB34	37.91061	-88.89636	2	2
Fulton	DJ08	40.49019	-90.34025	5	5
Grundy	DV04	41.28619	-88.36025	6	2
Hamilton	ATF07	38.01640	-88.46142	7	4
Henry	PBG12	41.51209	-90.08642	5	1
Iroquois	FLH02	40.80503	-87.86387	6	3
Jackson	ND01	37.77245	-89.17885	6	2
Jasper	BEG01	38.98528	-88.07517	7	7
Jefferson	NJ07	38.26935	-88.89863	7	6
Jersey	DZA02	39.07298	-90.49277	6	6
JoDaviess	MNI12	42.42453	-90.02321	5	5
Johnson	AJF16	37.46593	-88.75239	7	4
Kane	DTC03	41.74376	-88.54088	6	3
Kankakee	F02	41.16016	-87.66260	5	3
Kendall	DTCA01	41.63568	-88.54116	6	6
Knox	DJ02	40.90750	-90.08680	6	6
LaSalle	DR01	41.33326	-89.08116	4	3
Lawrence	BEAB01	38.76931	-87.86595	7	7
Lee	PBU10	41.76540	-89.16838	6	6
Livingston	DS06	40.83055	-88.57514	5	4
Logan	EID07	40.16032	-89.55138	5	5
Macon	E05	39.79667	-89.10430	6	6
Macoupin	DA05	39.25952	-89.84929	6	1
Marshall	DP02	41.08938	-89.31288	6	5
McDonough	DG04	40.33088	-90.89613	5	4
McHenry	DTK06	42.39957	-88.43074	6	3

Appendix I. continued

County	Identification code for Basin Survey Site	Location (decimal degree)		No. years surveyed	No. years mink detected
McLean	DKP02	40.59410	-88.88875	5	4
Monroe	OB04	38.18347	-90.05458	7	7
Montgomery	OIL01	39.30486	-89.42974	6	1
Morgan	DF05	39.86001	-90.33243	6	3
Moultrie	OT01	39.69520	-88.66193	6	6
Ogle	PQB04	42.10030	-89.05348	5	5
Perry	NCK01	38.15374	-89.38608	6	2
Pike	KCA03	39.58500	-90.71303	7	4
Pope	AJG18	37.44274	-88.70065	6	5
Pulaski	IX11	37.28450	-89.11803	7	4
Randolph	OA01	38.04624	-89.89245	7	7
Richland	CH01	38.71411	-88.11254	7	7
Saline	ATG03	37.70778	-88.49194	6	4
Sangamon	E26	39.83704	-89.54592	6	4
Schuyler	DGD01	40.11056	-90.71917	6	6
Shelby	OR02	39.33128	-88.67086	7	5
Stark	DJN02	41.16085	-89.73506	6	6
Stephenson	PWQ04	42.39909	-89.76280	5	3
Tazewell	DKG01	40.51833	-89.41395	5	5
Union	IC04	37.47117	-89.37677	3	3
Union	ICD02	37.45725	-89.34714	6	5
Vermilion	BPG11	40.30374	-87.62211	6	3
Warren	LDD20	40.95726	-90.62089	6	5
Washington	OJA01	38.44139	-89.41702	6	4
Wayne	CA07	38.43937	-88.62636	7	4
White	C32	38.16324	-88.14668	6	5
Whiteside	PH01	41.77219	-89.77211	6	4
Will	GBL02	41.71111	-88.12797	6	6
Woodford	DKKB01	40.77327	-89.11856	6	2

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Availability of Water for Voles in Green Vegetation Following a Period of Low Precipitation

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ABSTRACT

Free water within grasses and forbs from tallgrass prairie, bluegrass, and alfalfa habitats was measured at the end of a severe 2-month drought in east-central Illinois. There was sufficient free water within the plant tissues of both grasses and forbs in all three habitats to satisfy the water requirements of *Microtus ochrogaster* and *M. pennsylvanicus* while meeting their daily dietary requirements.

INTRODUCTION

Because dew formation and precipitation are sporadic, free water present in green vegetation is presumed to be the most consistent source of water for herbivorous arvicoline rodents inhabiting upland grasslands (Getz 1970). During periods of low precipitation, however, vegetation often appears dry and wilted, suggesting decreased free water within the plants. If so, low water availability in green plants during drought periods may adversely impact water balance of individuals and in turn population demography. There are, however, no data regarding amount of free water in plants during drought periods.

During the course of a study of population dynamics of the prairie vole, *Microtus ochrogaster*, and the meadow vole, *M. pennsylvanicus*, in east-central Illinois, I obtained data relating to free water present in green vegetation under drought conditions. Measurement of free water within the green vegetation in three habitats was obtained after two months of exceptionally low precipitation, when free water in the plants would be expected to be especially low.

METHODS AND MATERIALS

Study sites

Data were obtained from tallgrass prairie, bluegrass, and alfalfa habitats located in the University of Illinois Biological Research Area ("Phillips Tract"), 6 km NE of Urbana, Illinois (40°15'N, 88°28'W). The prominent plant species in the tallgrass site included: big bluestem, *Andropogon gerardii* (38%); Chinese lespedeza, *Lespedeza cuneata* (25%); Beard tongue foxglove, *Penstemon digitalis* (16%); and Indian grass, *Sorghastrum nutans*

(19%). All other species represented < 1% relative abundance (Getz et al. 1979). Relative abundances of plants in bluegrass were: bluegrass, *Poa pratensis* (70%); dandelion, *Taraxacum officinale* (14%); about 25 other species with relative abundances of ≤ 10% (Getz et al. 1979). Alfalfa (*Medicago sativa*) comprised approximately 75% of the vegetation in the alfalfa site. Other species included bluegrass; goldenrod, *Solidago*; timothy, *Phleum pratense*; brome grass, *Bromus inermis*; clover, *Trifolium repens* and *T. pratense*; and plantain, *Plantago* spp. (Getz et al. 1979).

Methods

Vegetation samples were taken during early afternoon on 3 August 1991. Precipitation the previous two months totaled only 8.12 cm, 13.25 cm (62%) below the previous 30-year average for the region (Illinois State Water Survey Local Climatological Data monthly summary for June-July 1991). Ten 0.25 m^2 circular frames were positioned at random in each site, utilizing a random numbers table and a 10-m small mammal live-trapping grid in the site. Sample sites were located at a 45° angle 5 m from the selected station to avoid bias from trampling of vegetation during the small mammal trapping of the sites. All vegetation within the frame was cut at the soil surface, sorted as to grasses and forbs, and placed in paper bags, the tare for which had been measured earlier. Tops of the bags were folded to avoid evaporative water losses. The bags were weighed and placed in the un-ventilated, un-cooled attic of Shelford Vivarium on the University of Illinois campus and the tops of the bags opened. Temperatures in the attic exceeded 40 °C most of the time. Thirty days later, when the vegetation was dry and brittle, the bags were weighed and water loss and proportion of the original wet weight of the vegetation that was comprised of free water calculated.

Data Analysis

The proportion free water in the vegetation was used to determine the amount of green vegetation needed to be consumed by the voles to meet daily water requirements (*M. ochrogaster*, 6.6 g/day; *M. pennsylvanicus*, 8.2 g/day; Getz 1963), assuming that free water in the vegetation was the only source of water. These values were compared with the average daily food consumption of the two species as reported elsewhere (*M. ochrogaster*, 16 g/day, Cole and Batzli 1979; *M. pennsylvanicus*, 29 g/day, Golley 1960). Although the food consumption data were from captive animals under laboratory conditions, they provided an estimate of total daily consumption of fresh green vegetation. These values are similar to those obtained by Bailey (1924) and others, as summarized by Golley (1960). Differences in water content of the vegetation among habitats was tested by use of one-way ANOVA and between grasses and forbs within habitats by *t*-tests (Zar 1999).

RESULTS AND CONCLUSIONS

Although measured at the end of a lengthy drought, except for grasses in bluegrass habitat, more than half the wet weight of both grasses and forbs in all three habitats consisted of free water (Table 1). Water content of forbs was greater than that of grasses in all three habitats. For grasses, those in the alfalfa habitat contained the most free water and those in bluegrass the least. Forbs were least succulent in tallgrass (Table 1).

The amount of food needed to be consumed to meet the daily water requirements (*M. ochrogaster*: alfalfa, grasses, 9.8 g and forbs, 9.4 g; bluegrass, grasses, 16.1 g and forbs, 9.2 g; tallgrass, grasses, 11.4 g and forbs, 10.8 g. *M. pennsylvanicus*: alfalfa, grasses, 12.2 g and forbs, 11.7 g; bluegrass, grasses, 20.0 g and forbs, 11.4 g; tallgrass, grasses, 14.1 g and forbs, 13.4 g) was less than that needed to meet daily dietary requirements in all three habitats. Because both species preferentially feed on forbs (Thompson 1965; Zimmerman 1965; Lindroth and Batzli 1984; Haken and Batzli 1996), individuals would easily meet their water requirements in the course of normal daily food consumption.

Getz (1963) reported that metabolic water production was sufficient to meet 15% of the water requirements of *M. pennsylvanicus* and 20% of that of *M. ochrogaster*. This would reduce the amount of free water needed to be obtained from the vegetation by individual voles. It appears, therefore, that even during periods of unusually low precipitation, there is adequate free water in green vegetation, including grasses, to meet the daily moisture requirements of both *M. ochrogaster* and *M. pennsylvanicus*. In this study, the entire plant was used in measuring free water. Much of the plant tissue in the samples included stems and old leaves, which would not be eaten by the voles. Most likely voles select the more succulent young leaves and stems or young shoots, which would be expected to contain more free water per gram plant tissue than does the entire plant.

Air humidity within the enclosed surface runways utilized by both species is relatively high at all times and does not adversely impact water balance of either species (Getz 1965, 1970, 1971). Evaporative water losses most likely are not sufficiently greater during these dry periods so as to result in water requirements greater than could be achieved from free water in the vegetation. I, therefore, conclude that water availability necessary to meet physiological requirements is not a factor influencing individual viability and in turn demography of either vole species. Unfortunately, population densities of both species were too low (< 5 voles/ha) in all three habitats throughout 1991 (Getz et al. 2001) to compare indices of physiological condition of individuals (body mass and proportion reproductive) in August 1991 with that during periods of normal precipitation.

Low population densities of *M. ochrogaster* and *M. pennsylvanicus* during spring-winter of 1991 (Getz et al. 2001) did not appear to be related to low precipitation during June-July of that year. Precipitation during April-May was 19.1 cm (10.1 cm above average); there was, however, no population growth of either vole species during the spring. Population densities of *M. ochrogaster* dropped from peaks in October 1990 in alfalfa, November 1990 in bluegrass, and December 1989 in tallgrass, to low densities by February 1991 (Getz et al. 2001). Population densities remained very low in all three habitats through the winter of 1992-1993. Population densities of *M. pennsylvanicus* were very low in all three habitats from at least 1989 through 1993. Precipitation during April-August 1992 was 62.7 cm (5.5 cm above average) and 32.9 cm September-November (11.6 cm above average).

Both species utilize small surface runways below the vegetation and detritus layer. Even though the vegetation in general appeared rather dry at the end of the drought, there was still ample cover for protection of the voles from predators.

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Utilization of the Exotic Cladoceran *Daphnia lumholtzi* by *Gambusia affinis*

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ABSTRACT

The exotic cladoceran, *Daphnia lumholtzi* Sars, possesses cyclomorphic features which are widely assumed to deter gape-limited predators. We presented adult *Gambusia affinis* with either *D. lumholtzi* or *Daphnia pulex* in effort to determine utilization of *D. lumholtzi* as a food source relative to a native prey item. Neither *D. lumholtzi* nor *D. pulex* were rejected by *G. affinis* more often than the other, but medium and large *Daphnia* were ingested more often than small individuals, regardless of prey species. These results suggest *G. affinis*, and therefore other gape-limited predators, may be able to utilize *D. lumholtzi* as a food source.

INTRODUCTION

As predator-prey interactions are a major driving force in freshwater community composition (Swaffar and O'Brien 1996), many zooplankters have developed mechanisms, both behavioral and morphological, to avoid predation by planktivores (Lysebo 1995). For instance, some taxa undergo diel vertical migration to escape predation (Zaret 1980, Williams and Pederson 2004). Others, particularly cladocerans, have developed cyclomorphological features to prevent ingestion by vertebrate, or gape-limited predators (Wetzel 2001). Gape-limited predators ingest their prey whole, and thus, maximum prey size is restricted to items that do not exceed the dimensions of the predator's mouth opening (Zaret 1980). *Daphnia lumholtzi* Sars is one such zooplankter that exhibits morphological features which may inhibit predation by gape-limited predators. In particular, *D. lumholtzi* possess lateral fornices, ventral spines, and pronounced anterior and posterior spines whose length can greatly exceed those of native *Daphnia* species (Swaffar and O'Brien 1996, Kolar et al 1997, Dzialowski et al 2000).

The natural distribution of *D. lumholtzi* includes southwestern Asia, Australia and most of Africa (Benzie 1988) where it can be found in habitats ranging from deep tectonic lakes to turbid temporary ponds. It was first reported in North America from Fairfield Reservoir, Texas in 1991 (Sorensen and Sterner 1992) and has since spread throughout much of the eastern half of the United States (U.S.G.S. 2001). The presence of *D. lumholtzi* in North American waters has been hypothesized to negatively impact planktivorous fish populations both by decreasing native prey abundance through competitive interactions (Kolar et al 1997, Lemke et al 2003) and by reducing predator feeding efficiency (Swaffar and O'Brien 1996). However, *in situ* experiments have concluded *D.*

lumholtzi can be utilized by planktivorous fish, but also suggest rejection of *D. lumholtzi* as a food source when gape limitation occurs, as in the case of juvenile fishes (Lemke et al 2003). Understanding the ecological relationship between gape-limited predators and *D. lumholtzi* is pertinent in that it considers the ability of planktivores to consume an non-native but potentially important food item.

Within this context we attempt to evaluate utilization of *D. lumholtzi* as a food source by a gape-limited predator. We also compare utilization of a native cladoceran, *Daphnia pulex* (Leydig) to that of *D. lumholtzi*. The western mosquitofish, *Gambusia affinis* (Baird and Girard, 1853) was used in this study as a model gape-limited predator because it remains planktivorous as an adult and is easily maintained in laboratory conditions (Carolina Biological Supply Company 2006, Manfield and McArdle 1998).

METHODS

Female *D. lumholtzi* were obtained by using vertical tows with an 80 µm mesh plankton net from Lake Barkley, an impoundment of the Cumberland River in western Kentucky. Individual females were placed in 30mL medicine cups filled with synthetic hard water (USEPA 1991) and incubated at 25°C on a 12-hour light/dark cycle. On alternate days, each female was fed approximately 1mL each of YCT (a mixture of yeast, powdered alfalfa leaves, and fish flake food) and a suspension of the green alga, *Selenastrum capricornutum* (USEPA 1991). Every third day the water in each medicine cup was replaced with fresh hard water. Both YCT and *S. capricornutum* as well as gravid *D. pulex* were obtained from Aquatic Biosystems, Inc., Fort Collins, Colorado. Female *D. pulex* were maintained in the same manner as was *D. lumholtzi*.

Upon maturity, females of both *Daphnia* species produced a clutch of one to fifteen neonates every 2-3 days. Offspring were incubated in their own individual medicine cups and allowed to mature for a specific number of days to produce sufficient individuals of a given size class as needed for predation experiments. In addition, ten individuals from each day class were removed and body length and total length measurements were obtained using an ocular micrometer. Body length was measured from the base of the head spine to the anterior end of the tail spine, while total length was measured as the distance between the termini of the head and tail spines. Age specific lengths were determined to ensure standard prey sizes in single and mixed species prey communities during predation experiments.

Approximately 100 *G. affinis* were obtained from Carolina Biological Supply Company, Burlington, North Carolina. Fish were divided equally among 5 10-gallon aquaria and fed tropical fish flakes daily as per label directions. For predation experiments, a single female *G. affinis* was randomly chosen and placed in a glass 2L trial chamber (2L cylindrical beaker) filled with 1 L of water gathered from the aquaria. Each fish was starved for 24 hours prior to the feeding trial and allowed to acclimate to laboratory conditions for 12 hours. At the conclusion of the acclimation period, each fish was offered 20 *Daphnia* from one of nine possible prey compositions, randomly chosen before trial initiation. Experimental prey composition could be 100% *D. lumholtzi*, 100% *D. pulex*, or 50% of each species and was composed of one size class that included either small (1-day old), medium (5-day old for *D. lumholtzi* and 7-day old for *D. pulex*), or large (11-day old)

individuals. Trials with a single prey item were used to assess the impacts of prey size on predation rates, while 50/50 trials were used to evaluate predator preference for a given species of prey. A piece of cardboard was placed behind the trial chamber to facilitate observation of fish behavior during trails. To avoid unnecessary disturbances, only the observer was present in the laboratory during each trial. All trials were conducted for a maximum of 5 minutes.

At the conclusion of each predation trial, *G. affinis* was removed from the trial chamber, euthanized, and placed in 70% ethanol. Body length, vertical gape length, and horizontal gape length were recorded for each fish. The water remaining in the trial chamber at the conclusion of each predation trial was filtered to remove any uneaten prey. These remaining *Daphnia* were identified and the number rejected was recorded. This process was repeated three times for each possible prey composition for a total of 27 trials.

We used 1-way ANOVA to compare frequency of rejection of individual prey items with size as the independent variable. In combined prey trials, we used 2-way ANOVA to determine significant differences in mean number of prey items remaining at conclusion of the combined prey trials. Significance of main effect variables and interaction of prey species and prey size were considered at a level of $\alpha = 0.05$. All statistical analyses were performed using SPSS 13.0 for Windows.

RESULTS

Mean *D. lumholtzi* body length ranged from 0.60 mm as neonates to 1.76 mm as adults, while mean total length ranged from 1.12 to 2.64 mm. Mean body length of neonate *D. pulex* was similar to that of neonate *D. lumholtzi* (0.65 mm), but upon reaching the adult instar, *D. pulex* had a mean body length of 2.19 mm. Mean total length of neonate *D. pulex* was 0.88 mm and 2.64 as adults, which is the same mean total length as adult *D. lumholtzi* (Fig. 1). With respect to general patterns of growth, body length of both *Daphnia* species were similar throughout the juvenile instars, although *D. pulex* body length surpassed that of *D. lumholtzi* upon reaching adulthood. *D. lumholtzi* possessed a longer total length throughout the juvenile instars, but adult individuals of both species were similar length (Fig. 1). Upon reaching the adult instar, total length of both prey species exceeds *G. affinis* gape length resulting in the potential for gape-limitation. Mean vertical and horizontal gape length of *G. affinis* was 2.48 and 2.22 mm, respectively.

Size classes of prey were established such that similar sized individuals of the two prey species were used during predation experiments. Small prey were 1-day old individuals with corresponding mean total lengths of 1.12 mm for *D. lumholtzi* and 0.88 mm for *D. pulex*. Individuals used for the medium prey size category had mean total lengths of 1.75 mm for *D. lumholtzi* (which corresponds to an age of 5-days old) and 1.77 mm for *D. pulex* (7-days old). For the large size class, both *D. lumholtzi* and *D. pulex* were 11-days old and had mean total lengths of 2.64 mm.

For 100% *D. lumholtzi* predation trials, *G. affinis* rejected a mean of 15.67 (± 0.67), 0.00 (± 0.0), and 3.00 (± 1.57) prey for small, medium, and large size classes, respectively (Fig. 2). *G. affinis* rejected small *D. lumholtzi* more often than either medium or large individuals ($F=552.22$, $P<0.01$ for medium prey; $F=57.76$, $P<0.01$ for large prey), but

there was no significant difference in rejection rates between medium and large size classes (F=3.86, P=0.12).

G. affinis rejected a mean of 15.33 (± 4.18), 0.00 (± 0.0), and 0.58 (± 0.33) prey for small, medium, and large size classes, respectively, during 100% *D. pulex* predation trials (Fig. 2). *G. affinis* rejected small *D. pulex* more often than either medium or large individuals (F=13.48, P=0.02 for medium prey; F=12.25, P=0.03 for large prey), but, as with *D. lumholtzi*, there was no significant difference in predation on medium and large size classes (F=4.00, P=0.12).

In order to test species-specific predation rates within size classes, comparisons of prey rejection were made for 50/50 predation trials (Fig. 3). When presented with small prey, *G. affinis* rejected a mean of 4.73 (± 2.73) *D. lumholtzi* and 3.51 (± 2.03) *D. pulex*. *G. affinis* rejected a mean of 1.53 (± 0.88) *D. lumholtzi* and 1.15 (± 0.67) *D. pulex* during medium size class trials. Finally, during large size class trials, *G. affinis* rejected a mean of 3.61 (± 2.08) *D. lumholtzi* and 0.58 (± 0.33) *D. pulex*. Neither the main effect of prey species (F=1.452, p=0.251) nor the interaction between main effect variables (F=0.368, p=0.70) were significant. However, predator rejection of small-sized individuals was greater than that the medium sized prey (F=4.342, p=0.038).

DISCUSSION

Regardless of prey species, we observed that *G. affinis* rejected small prey more often than medium or large prey. This may have resulted from difficulty in detection of small individuals, rather than from gape limitation. Gape-limited predators utilize visual senses to detect prey (Mills et al 1986, Wetzel 2001, Wissel et al 2003) and small *Daphnia* occupy less of the predator's visual field and possess a less conspicuous pattern of movement. Medium and large *Daphnia*, however, may not have escaped detection, and accordingly, were preyed upon at a significantly higher rate.

As *G. affinis* gape size was smaller than the total length of large sized individuals of both *Daphnia* species, one would expect large prey to be rejected more often than medium prey (Zaret 1980). However, there was no significant difference in predation on medium and large prey during this study. Even though total length of large prey items exceeded gape dimensions of *G. affinis*, capture of daphnids along their long axis would permit ingestion. Although not formally measured during predation trials, handling time of large prey appeared longer than that of small or medium prey, perhaps contributing to the high variability of rejection rates between individual trials.

Predation trials with 50/50 prey composition confirmed that *G. affinis* does not reject one prey species more often than the other. Similarity of total body length between the two prey species within a given size class likely accounts for this result. Although gape-limited predators often exhibit selectivity for certain prey (Kasumyan and Doving 2003, Keast and Eadie 1985, Link 2004), similar-sized individuals of *D. lumholtzi* and *D. pulex* may be similar with respect to other characteristics (e.g., movement patterns, overall visibility) that determine selection of prey by fish (Siefert 1972).

Previous studies (Lemke et al 2003, Swaffar and O'Brien 1996) focused on the potential impacts of cyclomorphic features on gape-limited predators, but did not consider preference of gape-limited predators when presented with both *D. lumholtzi* and native prey items. In this study we have determined predation rates may not differ between native daphnids and *D. lumholtzi* and that preference may be more dependant upon prey size as it relates to detectibility. This conclusion suggests *D. lumholtzi* may be utilized by planktivorous fish as a food source.

In our study, as with other laboratory experiments (Havel and Hebert 1993, Kappes and Sinsch 2002), cultured *D. lumholtzi* did not develop spines to a length typical of their wild counterparts. Since spine development in cladocerans often is triggered by the presence of both invertebrate and vertebrate predators, a lack of predatory cues in laboratory conditions often results in underdeveloped cyclomorphic features (Dzialowski et al 2003, Kappes and Sinsch 2002, Lysebo 1995, Work and Gophen 1995). Larger spines may augment total body length to the point where it exceeds predator gape size resulting in an overall reduction in available prey (Kolar et al 1997). Further analysis of interactions between *D. lumholtzi* with completely developed spines and gape-limited predators is necessary before the ecological impacts of this exotic zooplankter can be fully assessed.

SUMMARY

The widely accepted paradigm for evaluating impact of exotic species introductions is that they may interfere with ecological processes in the habitats into which they are introduced. In the case of *Daphnia lumholtzi*, concern derives from the potential displacement of native cladocerans with subsequent reduction in food resources available for planktivores, especially fish. This paper documents that extreme morphology of this exotic species does not deter a planktivore such as *G. affinis*, which preyed effectively on both *D. lumholtzi* and the native cladoceran, *D. pulex*. For either species, the only size class of individuals that were not preyed upon were those small enough to escape detection. A slight, but insignificant decrease in predation occurred with respect to those individuals with total body length approaching the gape dimensions of *G. affinis*. Based on these results, we conclude that pronounced head and tail spines of *D. lumholtzi* may not be sufficient to reduce risk to predation.

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Figure 1. Mean (n=10) total (body + spine) and body length of *Daphnia lumholtzi* and *Daphnia pulex*.

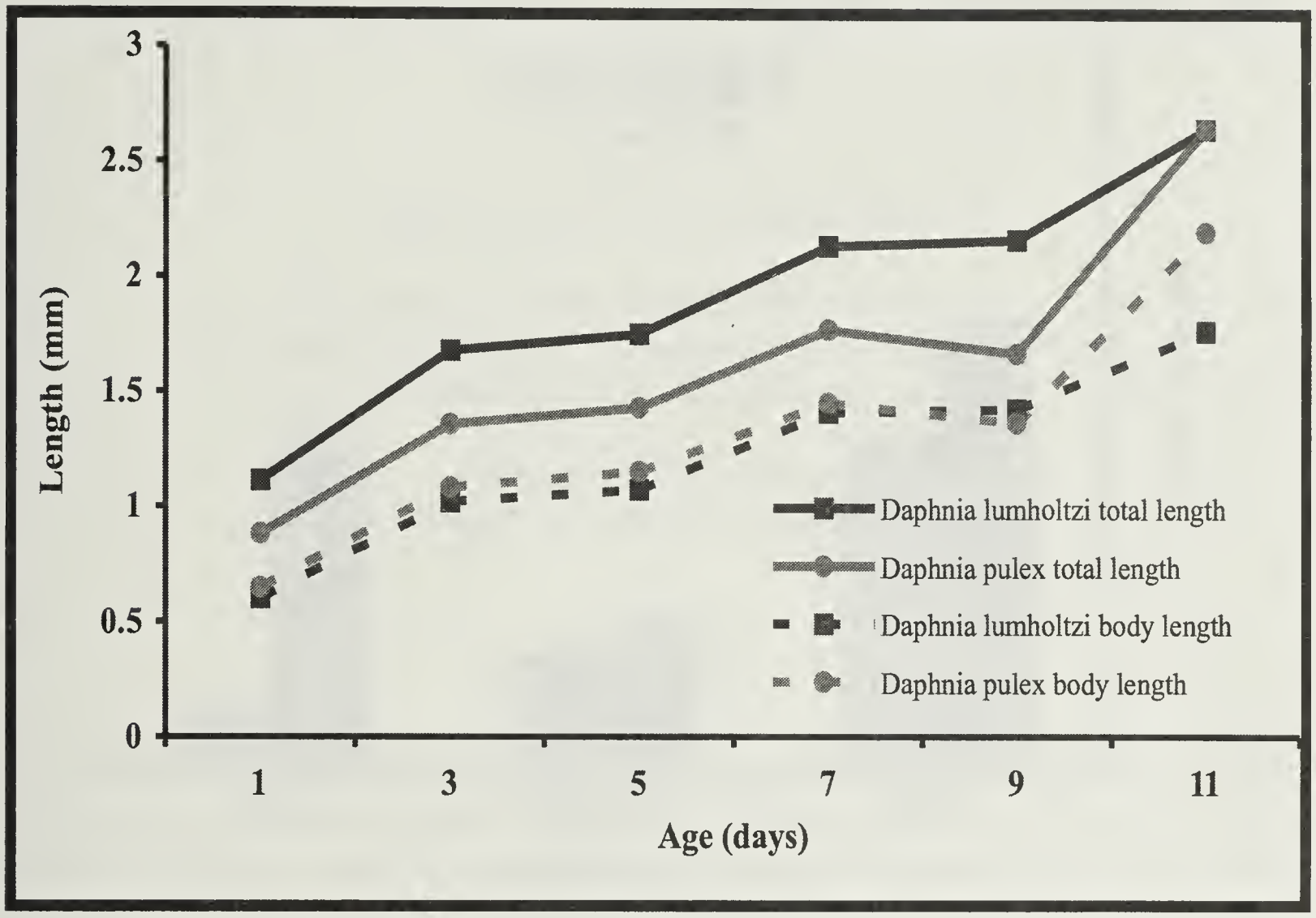


Figure 2. Mean (±1 SE) number of prey rejected during 100% predation trials (n=3).

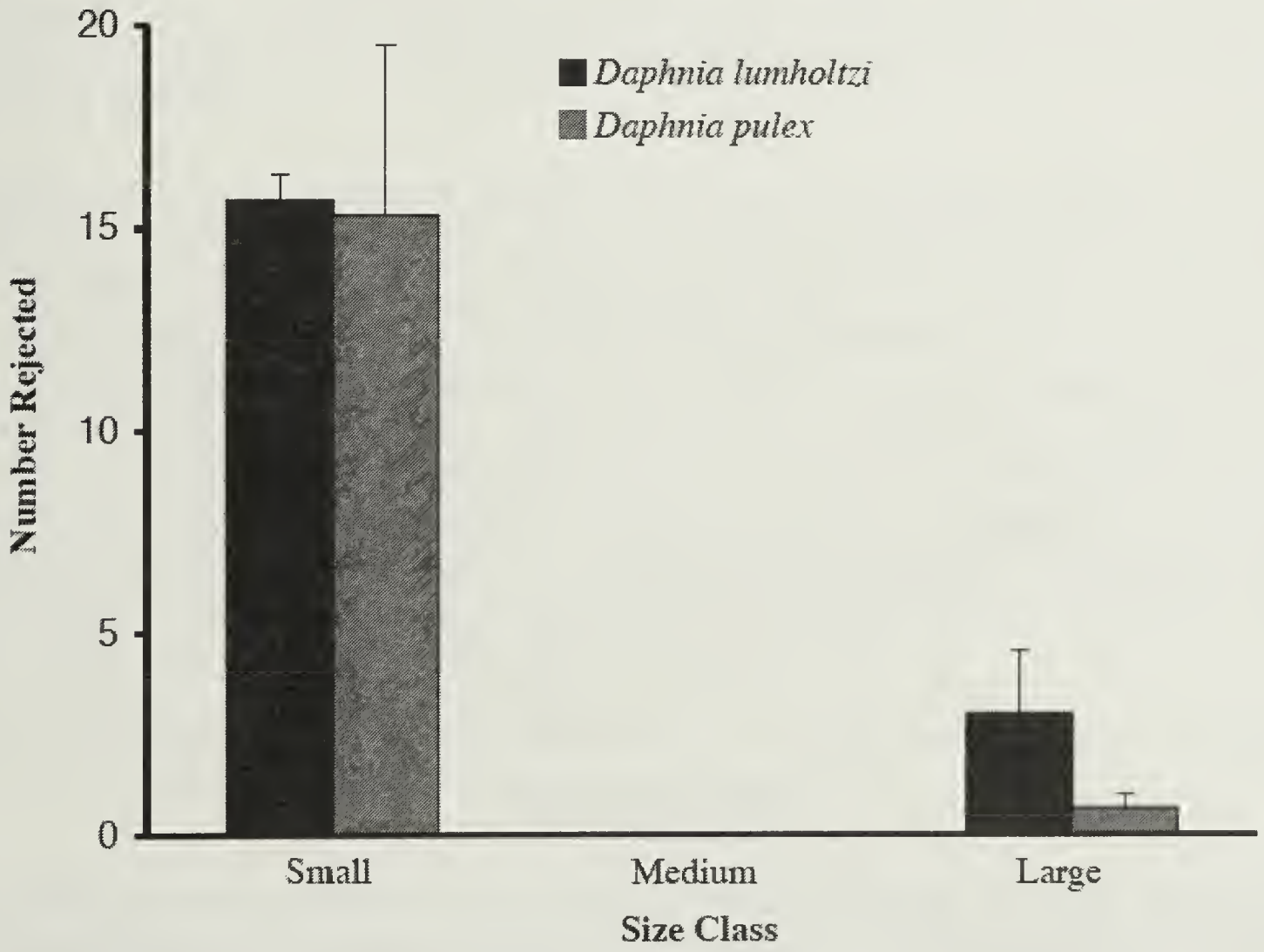
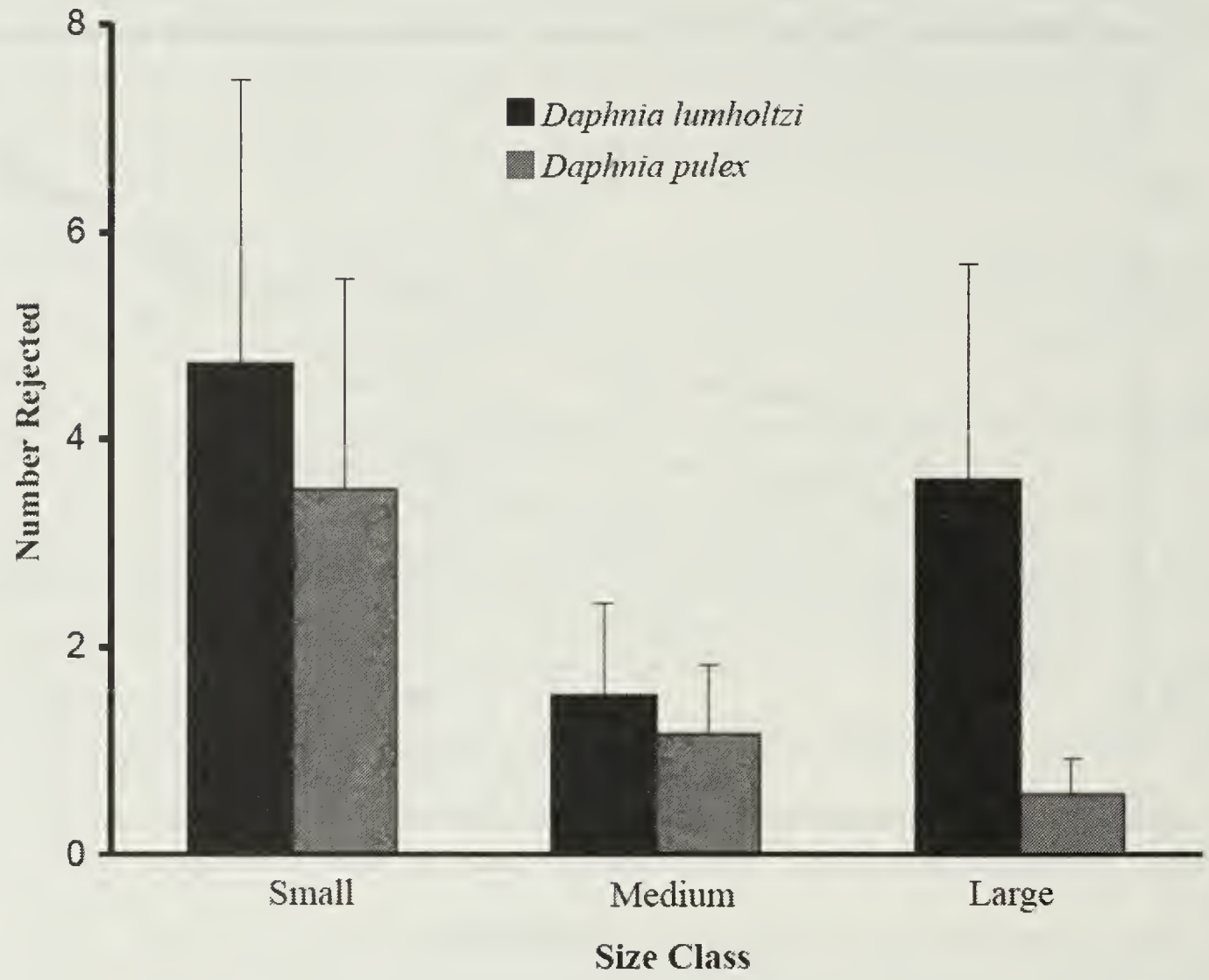


Figure 3. Mean (±1 SE) number of prey rejected during 50/50 predation trials (n=3).



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Current Conservation Status of the Blacknose Shiner, *Notropis heterolepis*, in Illinois

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ABSTRACT

Notropis heterolepis Eignemann and Eigenmann, the blacknose shiner, has been subject to extensive range reduction within the State of Illinois. We reviewed extant voucher material and conducted an intensive field survey of historical and likely localities to characterize the current conservation status (presently listed as endangered) of *N. heterolepis* in the state. Twelve historical lakes, 18 non-historical lakes, 20 historical streams, and 3 non-historical streams were surveyed. Presence of *N. heterolepis* in collections made at known historical localities was examined for three time periods that incorporated major sampling efforts: (a) 1877-1944, (b) 1947-1984, and (c) 1985-2003. Environmental variables discriminating lakes with a resident population from those where the species is absent are identified.

Populations of *N. heterolepis* in Illinois have become increasingly difficult to detect in historical stream systems and it continues to warrant endangered status. Glacial lakes with moderate to dense littoral zone vegetation in a sand substrate are systems most likely to contain a detectable and stable population. We illustrate that *N. heterolepis* populations can remain undetected for considerable periods of time (i.e., decades) when the species is present in low numbers leading to false assumptions of extirpation or absence at some localities. Thus, intensive and repeated surveys are necessary to adequately monitor its conservation status. Results indicate the observed decline is attributable to decreased abundance among extant populations as well as likely extirpations. Insight into population dynamics and other ecological aspects of *N. heterolepis* will allow for the development of informed management strategies in the future.

INTRODUCTION

The blacknose shiner, *Notropis heterolepis*, is widely distributed in North America but has been subject to significant localized reductions in the southern portion of its range.

Notropis heterolepis was described by Eigenmann and Eigenmann (1893) based upon one specimen (35 mm in length) collected from a tributary of the Qu'Appelle River at Fort Qu'Appelle, Saskatchewan (50°46'N, 103°48'W). The species also has been known in Illinois under the name *Notropis cayuga* (Forbes and Richardson 1920), in reference to a description by Meek (1888). However, the latter name was later placed in the synonymy of *Notropis bifrenatus,* a superficially similar and co-occurring species in the Lake Ontario drainage (Hubbs 1926). Two subspecies are currently recognized, *Notropis heterolepis regalis*, endemic to Harvey Lake, Michigan (Hubbs and Lagler 1949), and the nominate form *Notropis heterolepis heterolepis* occupying the remainder of the range.

The historical range of *N. heterolepis* was relatively broad, including the Atlantic, Great Lakes, Hudson Bay, and Mississippi River basins (Page and Burr 1991). Within these basins, the species occurred in well-vegetated lakes and pools of streams from Nova Scotia to Saskatchewan in the north, and from Ohio to Kansas in the south (Page and Burr 1991). Gilbert (1980) reported several populations from the middle Cumberland River drainage in north – central Tennessee. However, these were later described as *Notropis rupestris* (Page and Beckham 1987). Presently, the species is reported as stable and abundant in the northern half of its range, while in the south it is rare with highly localized populations that are declining or are already extirpated (Scott and Crossman 1973; Smith 1979; Becker 1983; Trautman 1981; Pflieger 1997).

The State of Illinois is at the southern extent of the historical range of *N. heterolepis* (Page and Burr 1991). In the first statewide survey of Illinois fishes, Forbes and Richardson (1920) reported that the species' range extended from the Des Plaines River drainage west to the Apple River drainage in the north, south to a locality on Hutchins Creek of the Clear Creek drainage in Union County. Most collections were reported from the Des Plaines, Fox, Rock, and Kankakee River drainages. It was most commonly collected from low gradient streams flowing through sandy soils and having connection to extensive prairie marsh areas, although its occurrence in the northeastern glacial lakes was noted. These conditions were apparently relatively common in the northern half of the state at the time, and probably explain the species' relatively broad distribution there (Forbes and Richardson 1920). This information presented a frame of reference for future investigators to gauge the conservation status of *N. heterolepis* in Illinois.

A second statewide survey of fishes (Smith 1979) characterized distributional changes of Illinois fishes resulting from landscape alteration occurring after the Forbes and Richardson survey. Continued presence of *N. heterolepis* was documented for the Fox River drainage and associated glacial lakes, the Rock and Kankakee River drainages. Also, a new population was recorded from Fairfield Ditch #1 of the Green River drainage. Collections from all other localities listed as exhibiting extant populations in Forbes and Richardson (1920) failed to yield any individuals, notably all collections made south of the Kankakee River drainage and in the Des Plaines River drainage, where it was formerly reported at multiple localities. It seems probable that stream populations had either diminished in size or were extirpated at several localities at this time (mid 1950's to 1973).

Page and Retzer (2002) reported the results of a status survey of Illinois' most rare fishes, including *N. heterolepis.* While several extant populations were reported for glacial lakes

in Lake and McHenry counties, the authors verified presence at only one stream locality based upon a vouchered specimen collected from the head of Nippersink Creek in McHenry County where it drains Elizabeth Lake.

Distributional surveys that produce vouchered records are the standard for determining conservation status of a fish species. However, specific localities are typically sampled only once during multi-year surveys and a decade or more may pass before a locality is re-visited. Accurate conclusions from surveys describing the status of a species are difficult when results are lacking relatively frequent, locality-specific temporal replication because sampling during a period of low abundance would increase the risk of falsely assuming absence.

To further knowledge about this imperiled species (currently listed as endangered in Illinois), our objective was to gain a more accurate understanding of the current conservation status of *N. heterolepis* by adding a greater degree of site-specific temporal replication to the survey conducted by Page and Retzer (2002). We predicted that a general negative trend in the probability of detecting *N. heterolepis* populations through time would be present, but also that repeated surveys would increase the number of extant populations identified.

METHODS

Collection Review

We reviewed vouchered collection material beyond that considered by Page and Retzer (2002) to account for previously unreported localities. We verified and recorded any collection data (e.g., locality information, date of collection, collectors, and comments) for all Illinois records of *N. heterolepis* at the Cornell University Museum of Vertebrates (CUMV), Field Museum of Natural History (FMNH), National Museum of Natural History (NMNH), University of Florida (UF), University of Michigan Museum of Zoology (UMMZ), Illinois Natural History Survey (INHS), and the Southern Illinois University at Carbondale Fluid Vertebrate Collection (SIUC). Collections at historical localities that did not yield specimens of *N. heterolepis* were noted so that locality specific sampling effort could be estimated through time. Only collections that contained other species likely to associate with *N. heterolepis* were considered in order to exclude collections that occurred in inappropriate habitats.

Conservation Status Survey

We sampled lake and stream systems to determine the presence or absence of *N. heterolepis*, with emphasis on systems having vouchered historical ("historical" systems, hereafter). Other systems within historical drainages without voucher material were targeted as well ("non-historical" systems). In total, 12 historical lakes, 18 non-historical lakes, 21 historical streams, and 3 non-historical streams were surveyed.

In general, sampling effort in historical streams was concentrated at, or as near as could be discerned, to previous collection localities, with additional sampling in localities with appropriate habitat. In non-historical streams, localities with habitats characteristically occupied by *N. heterolepis* were targeted.

In historical and non-historical lake systems, fish were collected from a number of randomly assigned 100-m x 10-m study reaches standardized according to shoreline perimeter. Because site-specific locality data were lacking and littoral zone habitat was often homogenous, we established the following protocol: 0 to 1500 m of shoreline was assigned three study reaches, 1501 to 3000 m of shoreline was assigned five study reaches, 3001 to 4500 m of shoreline was assigned seven study reaches, and >4500 m of shoreline was assigned nine study reaches. These were restricted to the littoral zone (i.e., extending 10 m out from shore) and were established parallel to the shoreline.

Methods of collection for both lake and stream systems included combinations of backpack electrofishing and seining with a 1.8 m x 9.1 m bag seine (3 mm mesh). Collections were preserved in 10% buffered formalin and returned to the lab for identification and vouchered in the SIUC Fluid Vertebrate Collection. Exceptions were made for adult individuals of readily identifiable species (e.g. *Micropterus* spp., *Lepomis* spp.), species of protected status, or when site-specific collection guidelines applied (e.g., at dedicated nature preserves).

Construction of Geochronologies

Status information garnered from our survey was combined with historical data obtained from the collection review in order to examine geochronological trends in overall and locality-specific presence or absence of *N. heterolepis* within Illinois. Collections were grouped into three time periods that incorporated major sampling efforts within the state: (a) 1877-1944, primarily Forbes and Richardson survey; (b) 1947-1984, primarily P.W. Smith survey; and (c) 1985-2003, primarily Page and Retzer survey and Roberts et al. survey. The number of reviewed collections with *N. heterolepis* present relative to the total number of reviewed collections for each time period was reported by lake or stream system on a map in order to present a visual representation of those sites harboring extant populations through time. Systems where *N. heterolepis* had been collected in time period (c) are those most likely to currently harbor extant populations. Stream and lake geochronologies were illustrated and described separately in order to facilitate identification of trends that may be dependent upon system type.

Habitat Discrimination

We characterized habitat for all historical lake systems visited in our survey and several non-historical lake systems in the glacial lakes region in order to identify discriminating habitat variables. These were placed into one of three categories based upon existence of extant voucher material. Historical lakes with individuals of *N. heterolepis* present in collections made within time period (c) were classified as "present," while those exhibiting voucher material only in time periods (a) and (b) were classified as "absent." Non-historical lakes were labeled as "non-historical."

Habitat parameters were quantified within the same study reaches established for fish collection. Each study reach was sub-divided into ten, 10-m x 10-m transects. A 0.25-m x 0.25-m square ring was tossed haphazardly twice at each transect. Vegetative cover (represented as % barren) and substrate composition (represented as % sand, % silt, % clay, % organic detritus, % gravel, % cobble, % boulder, and % shell detritus) were estimated from within the square for each toss. Depth was recorded for each toss location as well.

Assessments of shorezone characteristics and human impact were based upon United States Environmental Protection Agency (USEPA) lake and reservoir bioassessment guidelines (USEPA 2000). Bank erosion was scored on a scale of 0-4 at transects 1,5, and 10, with 0 representing no erosion and 4 representing severe erosion. Susceptibility to human encroachment was estimated by documenting the proximity of residential properties and roads to a 30-m line extending from the middle of transects 1,5, and 10. Scores of 0, 0.5, and 1 were given depending upon if a road or residential property was not present, present but adjacent to the line, or was within the 30-m line, respectively. Values recorded for all habitat parameters from each study reach were averaged to obtain individual, system-level means.

DATA ANALYSIS

All statistical analyses presented in this investigation were computed using JMP-IN software version 4.0.4 and SAS software version 9.1 (SAS institute, Cary, NC).

A G-test for independence was used to determine whether or not observations of presence were equally probable across time periods (a), (b), and (c). Those historical systems that had collections for all three time periods were used as replicates while those that had no collections reported for one or more time periods were excluded from the analysis. Also, because all but two historical lakes had no collections reported for time periods (a) or (b), only data from stream systems were analyzed.

Multivariate analysis of variance (MANOVA) was used to determine if "present," "absent," and "non-historical" lakes were significantly separated by the habitat parameters we measured. Canonical analysis (CA) was used to identify habitat variables that were principal discriminators between different lake categories. Data from Elizabeth Lake in McHenry County was excluded because access was limited to only a small portion of the lake and it was felt that the habitat characterization was not representative of the whole system. Percent boulder data was dropped from the analysis in order to lessen the amount of correlation existing between substrate variables and because substrate of this type was seldom represented in any of the lakes we characterized.

RESULTS

Collection Review

Review of the available voucher material yielded previously unreported collections of *N. heterolepis* from several localites including Coon Creek in McHenry County (FMNH 43458, 43480), Piscasaw Creek in McHenry County (FMNH 43358), Potawatomi Gravel Pit in Cook County (FMNH 61759), and Spring Creek in Will County (FMNH 61216). Misidentifications were corrected for collections from the Iroquois River in Iroquois County (CUMV 8149: 1 of 2 is *Hybopsis amnis*, 1 of 2 is *Notropis atherinoides*), an unnamed tributary to the Iroquois River in Iroquois County (CUMV 8143: 1 of 6 is *Notropis texanus*, 5 of 6 are *Hybopsis amnis*), Piscasaw Creek in McHenry County (FMNH 43342: 1 of 1 is *Notropis nubilus*), and Potawatomi Gravel Pit in Cook County (FMNH 61759: 1 of 195 is *Notropis heterodon*). No voucher material was present for records reported in Forbes and Richardson (1920) from the Embarras River, Wabash River, and

Clear Creek drainages in southern Illinois and therefore they were not considered in construction of the geochronology.

Conservation Status Survey

We documented an extant population of *N. heterolepis* at one of 21 historical stream systems (Fairfield Ditch No. 1: SIUC 50486) and six of twelve historical lake systems (Bangs Lake: SIUC 45775; Cedar Lake: SIUC 61325; Cross Lake: SIUC 50442; Deep Lake: SIUC 61330; Loon Lake: SIUC 45612; and Wooster Lake: SIUC 45601). No new populations were discovered from non-historical streams included in the survey while two additional lake populations were documented at Little Silver and Leopold Lakes in Lake County (SIUC 50404 and 42943, respectively). While the population in Little Silver Lake appears to be natural, the population in Leopold Lake is the result of introductions from nearby Deep and Cedar Lakes as part of a local conservation initiative

Geochronologies

Two of 21 historical stream sites have yielded individuals of *N. heterolepis* within time period (c). The G-test for independence showed that the probability of documenting the presence of *N. heterolepis* in historical streams is not the same across time periods (a), (b), and (c) ($G = 23.27$, $df = 2$, $P < 0.001$). Collections are less likely to include *N. heterolepis* now than during (a).

A majority of historical lake systems lacked reported collections for either time period (a) or (b), therefore trends in the probability of determining presence through time could not be analyzed statistically. However, eight of 12 historical lakes (all within Lake and McHenry counties) (Figure 2) have vouchered collections for time period (c). The status of a population reported for Nippersink Lake in time period (a) is unknown because no collections exhibiting species associated with *N. heterolepis* have been reported since that time.

Habitat Discrimination

MANOVA revealed that "present", "absent", and "non-historical" systems were significantly separated by the habitat parameters we measured (Wilks' Lambda: $F = 2.08$, $df = 22$, $P < 0.05$). Two canonical dimensions were identified that explained 66.7% and 38.3% of the variation in our data, respectively. Canonical dimension one primarily represented a substrate gradient from organic detritus to sand, while canonical dimension two primarily represented a gradient of percent vegetative cover. In general, CA indicated that historical lakes had predominately sand substrates while organic detritus was more dominant in "non-historical" lakes. "Absent" systems were differentiated from these in having a proportionally greater amount of shoreline area that was barren of vegetative cover (Figure 3).

DISCUSSION

Conservation Status in Stream Sytstems

Notropis heterolepis is in danger of extirpation from stream systems in Illinois as indicated by a significant decrease in the probability of successfully collecting specimens through time. However, the current distribution of *N. heterolepis* in streams is obscured due to difficulty documenting extant populations. A good example is the population in

Fairfield Ditch No. 1 of the Green River Drainage. *Notropis heterolepis* was first collected here on 17 July 1963 (INHS 12654, N = 1) but not documented again until 5 June 2003 (SIUC 50486, N = 2), even though four collections from the same general area were made in the interim that included an otherwise similar assemblage of species.

Population dynamics are a likely explanation for difficulty in documenting the presence of *N. heterolepis* in streams. Stream populations of *N. heterolepis* in Illinois may exhibit pronounced inter-annual fluctuations in abundance. Year-class strength for populations of fishes occurring at the range periphery can vary greatly due to the influence of environmental, density-independent effects. This is because conditions necessary for some life history functions occur more sporadically on the periphery than for those occurring in more central locations (Lawler 1965). For southern populations of *N. heterolepis* already existing in low numbers due to habitat degradation, further reductions in abundance that are the result of environmental, density-independent effects likely increase the risk of localized extinction and lead to distributions that are patchy and dynamic through time.

Conservation Status in Lake Systems

Nine extant populations of *N. heterolepis* are known from glacial lake systems of the Fox River drainage found within Lake and McHenry counties. A majority of these populations have only been documented within the past 20 years, coinciding with the first reported collection attempt at many of these locations. Also, records for Cedar Lake, where collections were made for all three time periods, indicate that the species has persisted there since at least 1882. It is probable that several glacial lakes in the region have historically harbored populations of *N. heterolepis* that still persist today, although recent introductions cannot be ruled out (e.g., bait bucket introductions).

CA indicated that moderate to dense vegetation over sandy substrates in the littoral zone was associated with detectable *N. heterolepis* populations. This supports results reported by Roberts et al. (2006) that indicate littoral vegetation is vital to trophic and reproductive aspects of *N. heterolepis* life history.

CONCLUSIONS

The decreased probability of detecting *N. heterolepis* at historical stream localities through time leaves no doubt that the species is imperiled within Illinois. However, under conditions of duress, the species can persist in streams with densities or distributions that make them difficult to detect via traditional sampling techniques. Thus, intensive and repeated surveys are necessary to identify those streams that harbor extant populations. The population within Fairfield Ditch No. 1 in Bureau Co. should receive further study. Investigations into population structure and stream life history characteristics will benefit conservation initiatives in the future. Temporal trends in abundance and distribution should be characterized so that stream surveys can be conducted at times and in locations that are optimal for detecting the presence of *N. heterolepis*.

Notropis heterolepis populations in glacial lakes appear stable but occur in only a small number of these. Immediate steps need to be taken to maintain the integrity of the nine glacial lakes known to harbor extant populations (Figure 2). Managers should ensure that

moderate to dense vegetation is maintained in littoral areas so that suitable feeding and reproductive habitat is available (Roberts et al. 2006).

The documented decline of *N. heterolepis* in Illinois and other Midwestern states may be a harbinger of an overall decline in the ecological integrity of aquatic systems in this region. A broad review characterizing the structure and status of fish assemblages inhabiting Midwestern lakes and streams that incorporates aspects of individual species life history would provide insight into larger trends in ecological structure and function of these systems.

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Figure 1. Lotic geochronology of *Notropis heterolepis* in Illinois. Lines refer to localities with extant voucher material reviewed from three time periods that incorporated major sampling efforts within the state: a (1877 – 1944), b (1947 – 1984), and c (1985 – 2003). Locality specific data are: number of reviewed collections with *N. heterolepis* present, relative to the total number of reviewed collections for each time period. Localities with individuals of *N. heterolepis* present in collections made during time period c are those most likely to still have extant populations.

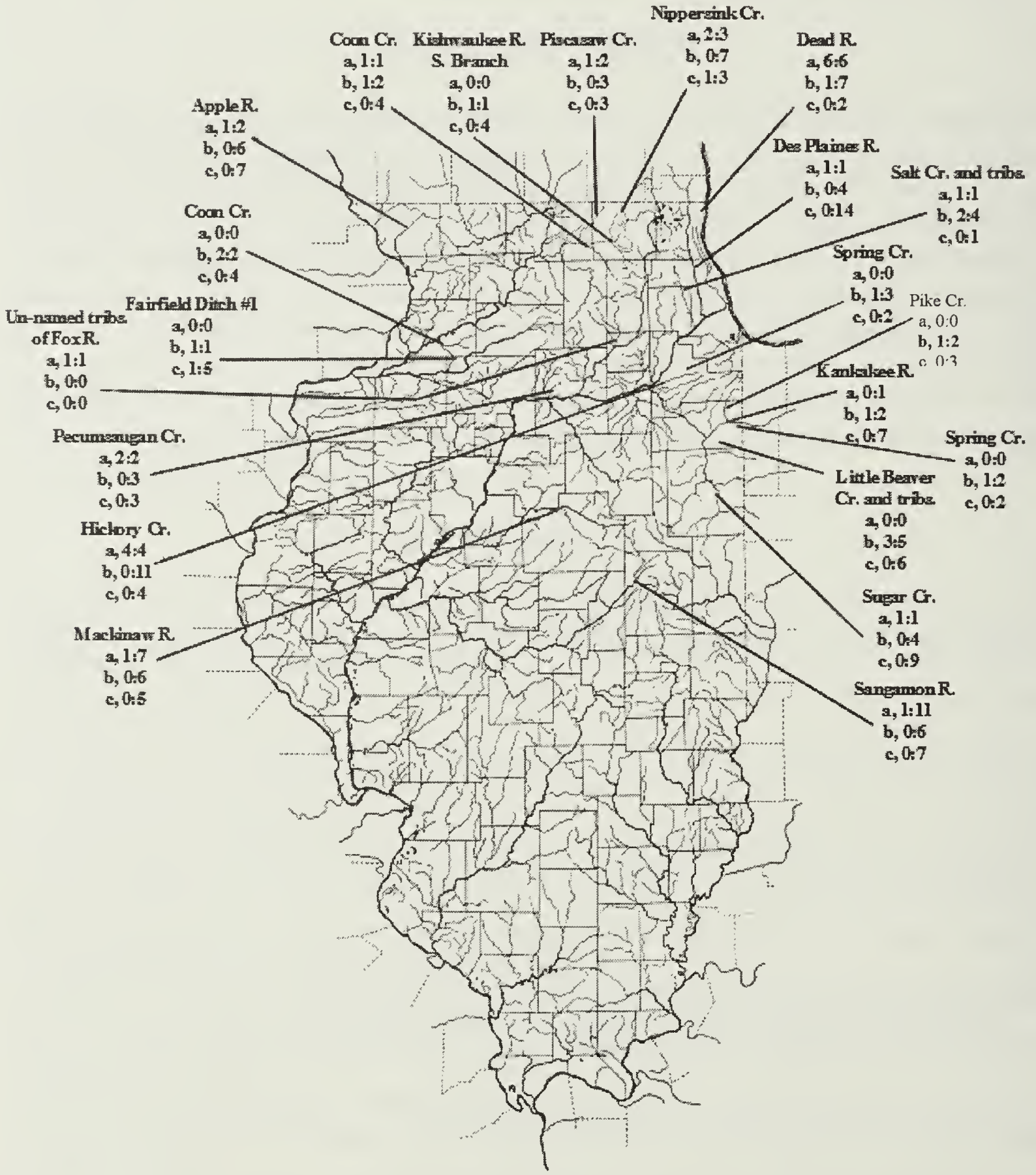


Figure 2. Lentic geochronology of *Notropis heterolepis* in the glacial lakes region of northeastern Illinois. Lines refer to localities with extant voucher material reviewed from three time periods that incorporated major sampling efforts within the state: a (1877 – 1944), b (1947 – 1984), and c (1985 – 2003). Locality specific data are: number of reviewed collections with *N. heterolepis* present, relative to the total number of reviewed collections for each time period. Localities with individuals of *N. heterolepis* present in collections made during time period c are those most likely to still have extant populations.

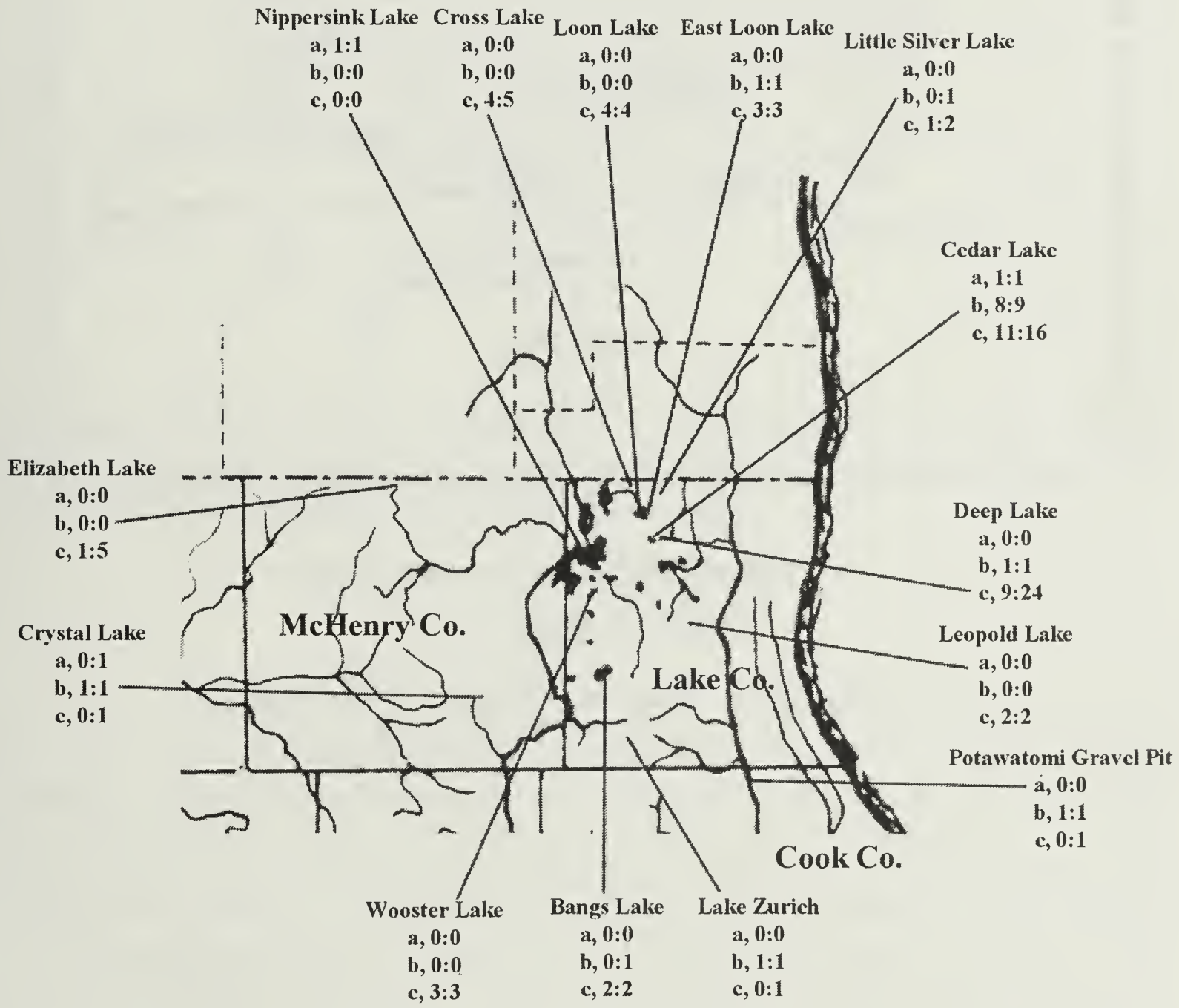
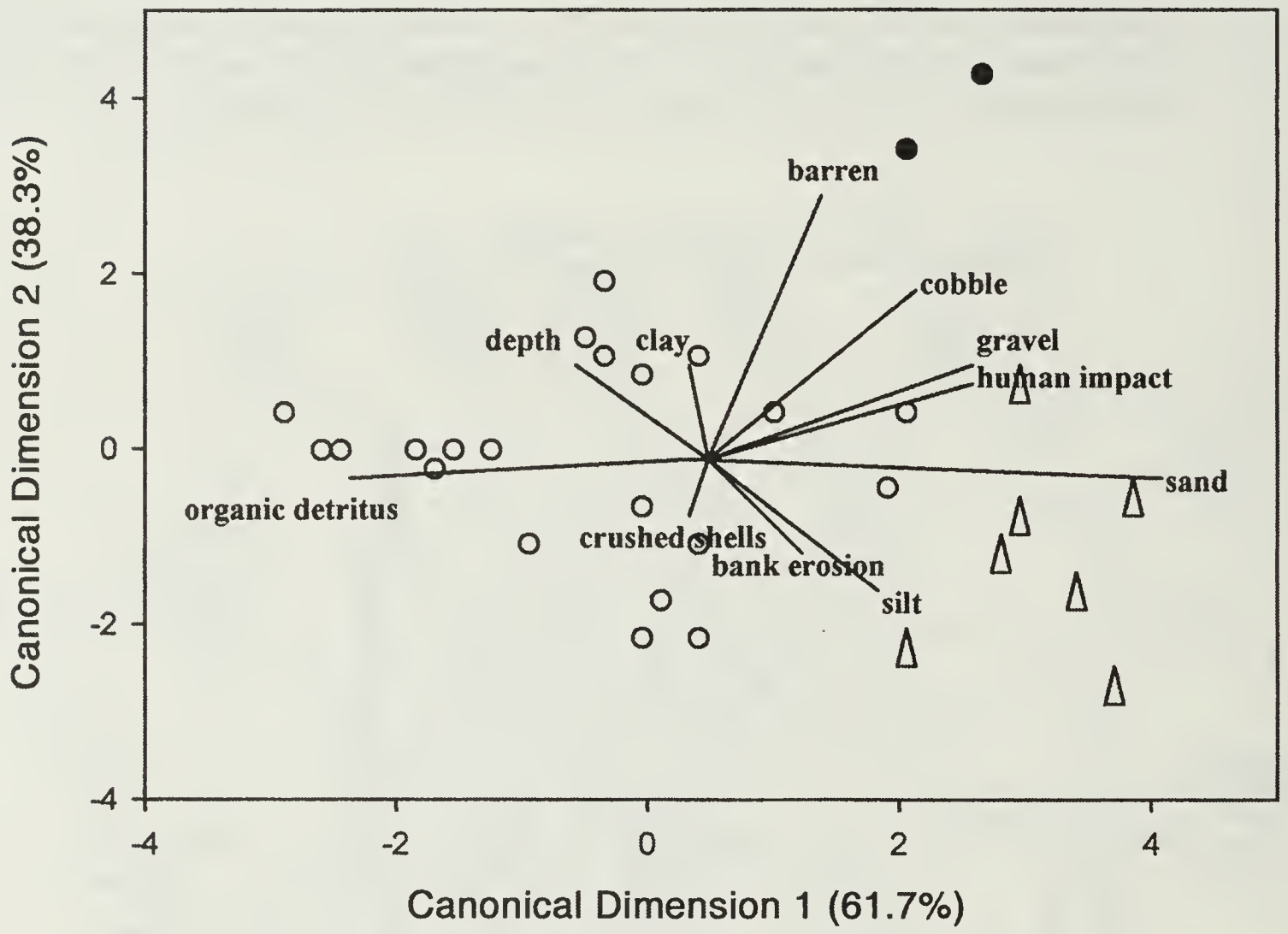


Figure 3. Habitat characteristics of present, absent, and non-historical lakes described within two canonical dimensions. Axes within the plot represent individual habitat parameters where length of the axis for each parameter corresponds to its overall explanation of among-class variation.



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The First Record of the Eastern Small-footed Myotis (*Myotis leibii*) in Illinois

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ABSTRACT

The eastern small-footed myotis (*Myotis leibii*) is one of the least known bats in eastern North America. We document the first record of the species in Illinois, and discuss possible reasons it has not been reported in the state until now.

INTRODUCTION

The eastern small-footed myotis (*Myotis leibii*) is one of the smallest, least common, and more elusive species of bat in North America (Best and Jennings, 1997; Bogan, 1999). Its geographic range extends from Quebec, Ontario, and Maine south through the Appalachian Mountains and west to Arkansas and Oklahoma (Best and Jennings, 1997). The species is generally associated with mountainous regions (Best and Jennings, 1997; Whitaker and Hamilton, 1998) and eastern hardwood and coniferous forests (Bogan, 1999), although information on specific summer habitat requirements is limited. It enters hibernation later than its congeners – in November or early December – and leaves earlier in the spring (Bogan 1999). The rarity of *Myotis leibii* is suggested by its listing as endangered, threatened, or a species of special concern in 8 of the 21 states where it is thought to occur. Neither Whitaker and Hamilton (1998) nor Bogan (1999) included Illinois within the geographic range of the species. There is only one historical record of *M. leibii* within 160 km of Illinois, a specimen taken in southeastern Missouri in 1949 (Hoffmiester, 1989). The nearest record from Kentucky is from near Fort Knox, Breckinridge County (J. MacGregor, personal communication), approximately 200 km from the Illinois border.

RESULTS AND DISCUSSION

On 4 November 2005, we found a male and a female *M. leibii* in torpor at Fink Sandstone Barrens Natural Area, Pope County, Illinois (T12S, R4E, Sec 1 NE ¼; elevation 188 m). The bats were roosting together under a relatively smooth rock approximately 0.5 m in diameter that was among other scattered rocks on exposed sandstone bedrock. We retained the male for a voucher specimen (skin and skull No. 4317 Mammal Museum, SIUC Department of Zoology). The female was released because we felt one voucher specimen was sufficient. She flew a few meters away from the original spot and crawled under another rock. These specimens represent the first verified records of *M. leibii* in Illinois. Body weight of the male was 5.8 g and there was extensive subcutaneous fat deposited in the abdominal region and lower back, suggesting the animal was about to enter hibernation. Standard body measurements (mm) were: total length 72; tail length 25; hind foot length 7; ear length 13; forearm length 30; and tragus length 9. The greatest length of the skull was 13 mm; there was no sagittal crest. There were 2 upper incisors in each quadrant, with 2 small premolars posterior to the upper canine. Maxillary and mandibular premolars and molars were 6/6 in each quadrant. Body measurements, skull and dental characteristics of the specimen are consistent with those of *M. leibii* and confirm our initial identification.

There are several possible reasons why *M leibii* has never been documented previously in Illinois, despite often extensive surveys of bats by previous investigators (Whitaker and Winter, 1977; Hofmann et al., 1999; Carroll et al. 2002). It may be that relatively little work has been conducted in habitats occupied by *M. leibii*. While there is ample potential summer and winter habitat in southern Illinois, many of the investigators working with bats have concentrated their efforts on the federally endangered Indiana bat (*M. sodalis*), a species found in bottomland hardwood forests (Gardner et al. 1996; Carter and Feldhamer 2005). Thus, researchers are less likely to encounter the small-footed myotis. In addition, *M. leibii* may be difficult to detect in cave or mine hibernacula because they often occur alone or in small groups under rocks and in fissures in the floor, roof, and walls (Best and Jennings, 1997; Bogan, 1999). They are much more likely to be overlooked than *M. sodalis* for example, which generally occur in easily recognized clusters on the walls or ceilings. Also, if seen, they may be misidentified because researchers in Illinois do not expect to find them.

We suspect that *M. leibii* is more widely distributed in suitable habitat in southern Illinois beyond the single location we report here. The species is very distinctive in the way that it roosts. Whereas most bats hibernate with their wings parallel to the axis of the body, *M. leibii* may extend its wings at a 30° angle (Whitaker and Hamilton, 1998). Mohr (1936) considered this characteristic "a very definite means of identification at a distance." While conducting hibernacula surveys on the eastern side of the state during the winters of 2003 and 2004, we observed several bats hibernating in this fashion. One of these individuals also had a dark facemask, characteristic of *M. leibii*. The bats could not be retrieved from the ceiling of the mine, and because small-footed myotis had not been documented from the state, we did not consider the taxon as a viable option. Also, during surveys of bats at Mermet Lake State Forest and Conservation Area, Massac County, during the summers of 2004 and 2005 using Anabat acoustic detectors, the echolocation signature of *M. leibii* was recorded three times at three separate locations (J. Wolff,

unpublished data). Although we do not consider this definitive evidence of the occurrence of the species there, it is suggestive of wider distribution of the species in Illinois.

As with many chiropterans, there are limited data on the natural history and status of *M. leibii*. Further studies are warranted to determine the distribution, habitat requirements, and population status of the small-footed myotis in southern Illinois and many other states throughout its range where it currently is listed.

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BOOK REVIEW 2006 - #1

Drlica, Karl. Understanding DNA and Gene Cloning: A Guide for the Curious. Fourth Edition. 2004. xiv + 369 pages; text; illustrations; photographs; questions for discussion; additional reading; glossary; index. John Wiley & Sons, Inc., Hoboken, New Jersey. ISBN: 0471-43416-7. Soft Cover. Price: US $44.95 Available from John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030.

Understanding DNA and Gene Cloning by Drlica stands apart from the numerous texts of molecular biology and genetics written for a general audience, for a variety of reasons. First, the author has succeeded in presenting in-depth concepts without relying on diagrams of chemical structures and equations. This makes the book more accessible to a wider audience. Second, each chapter concludes with an insightful "Perspective" section, which relates each chapter's concepts to historical and contemporary issues. Third, each chapter contains a set of "Questions for Discussion" that is both analytical and provocative.

The first two parts of Drlica's book, on "Basic Molecular Genetics" and "Manipulating [Deoxyribonucleic Acid] DNA," are well-written and full of helpful diagrams. There is an emphasis on basic molecular biological and microbiological techniques that will give readers, especially those new to molecular genetics, a good feel for the ways in which researchers have achieved the current level of understanding about macromolecules and cells. Techniques such as buoyant density centrifugation, filter hybridization, and colony hybridization are presented in a clear, concise manner, aided by excellent drawings and flow charts. Instead of needlessly sub-dividing the techniques in an encyclopedic fashion, Drlica organizes the major cloning techniques based on broader themes. For example, Chapter 8 presents the many techniques that rely on base pairing. As I often tell my students, if one has a good understanding of the parameters governing how nucleic acid molecules hybridize with each other one can easily understand dozens of the experimental techniques, some rather sophisticated, being used by molecular geneticists today.

Chapters 9 and 10 synthesize the techniques described in the earlier chapters, demonstrating how one can use the experimental tools to clone a eukaryotic gene and ultimately deduce its structure and function. Drlica pays homage to one of the seminal experiments in the history of molecular biology by describing the cloning of the rabbit beta-hemoglobin gene, which was the first mammalian gene cloned (in 1978). Chapter 10 gets a little bogged down in rather esoteric topics (use of phage M13 in DNA sequencing, and DNA footprint analysis), but otherwise flows nicely.

The second half of Understanding DNA and Gene Cloning presents various topics sure to intrigue a wide audience. Drlica presents well-crafted overviews of specific areas of investigation, most of which garnered Nobel prizes for their primary discoverers. These include ribonucleic acid (RNA) splicing by ribozymes, the production of antibody diversity by DNA rearrangement, and transposable genetic elements. Two chapters focus on arguably the two greatest health problems facing the world's human population today: acquired immunodeficiency syndrome (AIDS) and cancer. The chapter on AIDS approaches the problem from the point of view of the causative agent, the retrovirus (1), and the chapter on cancer focuses on the way in which genes, in somatic tissue, can

become altered in ways that affect the regulation of cell growth and cell death. In Chapters 14 and 15, Drlica does an admirable job of summarizing the important concepts of human genetics and genetic diseases, and the ways in which DNA-based techniques can be used to screen for genetic disorders, treat some disorders, and establish relationships (e.g. paternity or forensic) among individuals or events. The book closes with a summary of the field of genomics (2) that even a general audience will find very understandable – no small feat! Drlica provides a nice treatment of comparative genomics as well as functional genomics. He does not overwhelm the reader with too much emphasis on bioinformatics (3), and he provides a clear description of how DNA microarrays (4) are used in modern molecular genetics research.

Drlica's Understanding DNA and Gene Cloning is a very versatile and carefully written guide for a wide audience. Most impressive are the thought-provoking essays that conclude each chapter. These closing comments do indeed offer a wider "Perspective" on the topics presented in each chapter. Finally, I have a special admiration for the well-crafted, analytical questions posed at the end of each chapter. Students of molecular genetics would do well to read this book, for the value of the questions alone.

Explanation of Selected Terms:

1. Retrovirus – A type of single stranded RNA virus which encodes a reverse transcriptase enzyme capable of generating a DNA copy of the viral genome.
2. Genomics – A discipline characterized by the global analysis of gene structure as revealed by the entire DNA sequence of an organism's genome.
3. Bioinformatics – Application of computational tools for expanding the ability to acquire, organize, analyze, or visualize biological data.
4. DNA Microarrays – Robotically generated slides or chips consisting of an ordered grid of defined, synthetic DNA molecules representing specific clones or genes, usually numbering in the thousands.

Reviewer: Mark A. Erhart, Professor of Molecular Biology, Department of Biological Sciences, Chicago State University, Chicago, IL 60628.

BOOK REVIEW 2006 - #2

Chagnon, Stanley A., James R. Angel, Kenneth E. Kunkel, and Christopher M.B. Lehmann. Climate Atlas of Illinois. 2004. x + 309 pages; tables; figures; black and white photographs; colored photographs; three chapters with literature citations; bibliography; glossary; two appendices. Illinois State Water Survey, Informational/Educational Material 2004-02 (ISWS IEM 2004-02), Champaign, Illinois. Soft Cover. Price: $20.00. Available from: Illinois State Water Survey, Attention: Gloria Marsh, 2204 Griffith Drive, Champaign, IL 61820

Cold waves, heat waves, droughts, floods, and storms of all types; "If you don't like the weather, just wait, it will change" is a common expression used to describe weather conditions in mid-latitudinal locations, as exemplified by the continental interior of the United States, especially the state of Illinois. Sometimes dramatically, sometimes rapidly, but most likely in a regular and recurrent fashion, the weather of Illinois is often changeable and unpredictable.

What are the key factors that control the climate of Illinois? First of all, the state's continental location, mentioned above, eliminates the potential moderating influences of oceans. Therefore, continentality is the dominant control, save for the localized effects of Lake Michigan in the northeastern part of Illinois. Because of the mid-latitudinal location, the amount of solar energy varies greatly from summer, with its longer days and higher sun angles, to winter's short days and low sun angles. As a consequence, summers tend to be rather warm while winters are cold, conditions reinforced by the continental location as well. Secondly, the central location of Illinois allows the state to be affected by cold, dry air masses originating far to the north and northwest in northern Canada (dominant in winter), as well as by warm, humid air masses from the Gulf of Mexico to the south (dominant in summer). Pacific air from the West Coast frequently reaches Illinois, but in a modified form, having lost most of its original moisture supply crossing up and over the Western mountains. Thirdly, active weather systems, including high pressure centers, low pressure systems, and frontal boundaries, cause highly variable weather conditions as they move across the state in a general west-to-east direction following the large-scale westerly circulation found in the mid-latitudes. Also, typical of mid-latitudinal continental climatic regions are four distinct seasons, each characterized by different climatic conditions.

Furthermore, the authors identify several distinctive and unique aspects of the climate of Illinois. Significant north-south contrasts in temperature are found within the state. A wide variety of different types (and amounts) of precipitation occur as well, with both strong monthly and seasonal variations found. Weather conditions often exhibit marked variability between different areas of the state, and particularly from year to year. Finally, large numbers of different storms occur in all seasons (snow and ice storms in winter, and severe weather - thunderstorms, hailstorms, flash floods, and tornadoes - during the warmer months). In addition, particular areas of Illinois experience special local and regional climatic conditions: lake effects adjacent to Lake Michigan in northeastern Illinois; urban effects produced by the large metropolitan areas of Chicago and St. Louis; and topographic effects caused by the hilly terrain in southern Illinois. The Climate Atlas

of Illinois provides a comprehensive and detailed examination of the state's climate encompassing these local and regional effects, and other climatic impacts as well.

One of the most interesting features (to me) contained in the Climate Atlas of Illinois is the detailed descriptions of noteworthy weather events. Many of these have occurred in the last 10-15 years, a time frame in which our lives may have been personally affected. Summer heat waves and outbreaks of Arctic cold in the winter are not uncommon occurrences in Illinois. Record-setting heat waves have affected the state in July 1936 (during the Dust Bowl era), July 1954 (setting the highest temperature ever recorded in Illinois, 117°F in East St. Louis), and again more recently in July 1995 and 1999. Heat can prove deadly as well, with a record 753 deaths in Chicago in 1995. It is interesting to note that heat waves represent the single, most deadly climate hazard in Illinois. Cold waves rank second; record cold temperatures were felt in February 1899 (more than 100 years ago) and more recently in February 1996.

Extreme seasonal variability also characterizes precipitation patterns. Droughts are a recurring part of climatic conditions. The driest conditions were found during the decade of the 1930s, with 1934 and 1936 standing out because these years were accompanied by intense summer heat, which exacerbated the effects of the drought, especially on agriculture. The drought of summer 1988 was actually the middle of a consecutive three-year period of dryness. Not only were crop yields significantly reduced, the lack of sufficient rainfall created serious shortages in municipal water supplies. Low water levels in streams and rivers also led to disruptions in river transportation on the major rivers in the state. As it turns out, flooding in Illinois actually causes the most financial damage, and flood losses have increased significantly in recent years. Since 1983, average annual losses from flooding have amounted to $257 million, the third highest total in the United States. The Great Flood of 1993 was unprecedented in its magnitude, duration, and impact. A persistent weather pattern led to an extended period of heavy rainfall, and resulted in widespread catastrophic flooding on all major rivers across the Upper Midwest, including the Illinois and Mississippi Rivers. Damage from the Great Flood totaled $1.6 billion in Illinois alone, from agricultural losses, flooded homes, levee failures, damage to roads, bridges, and other structures, and transportation disruptions (road, railroad, and barge traffic).

Severe storms also cause considerable damage, and some deaths, as a result of heavy rain-producing thunderstorms (and flash floods), lightning, hail, wind, and tornadoes. The list of outstanding weather events features all of these types of storms. Notable on the list is the Tri-State Tornado on March 18, 1925, the single longest tornado track on record. The storm covered 219 miles from southeastern Missouri across southern Illinois into southwestern Indiana, moving rapidly at speeds exceeding 60 mph. This monster tornado was one-half to one mile in width and resulted in 695 deaths and more than 2000 injuries. The more densely populated coal-mining region around Murphysboro, Illinois suffered the most death and destruction. The Climate Atlas of Illinois describes other major storm events as well.

Not to be overlooked are severe winter storms with their often deadly combinations of heavy snowfall, strong winds, and biting cold. Based on snowfall totals, areal coverage, and damage costs, the authors identified the January 26-27, 1967 storm as the worst

(Chapter 8, Page 235). A record 24 inches of snow fell in Chicago, while freezing rain plagued southern Illinois. High winds caused excessive drifting of snow, completely paralyzing travel across the state, and in the city of Chicago in particular. Storm losses totaled $197 million (in 1967 dollars; $1.6 billion in 2002 dollars) from the combination of economic losses, business closings, power outages (especially in the ice-covered parts of south-central Illinois), and snow removal efforts. Snowstorms can be expected during any year. Another January blizzard, this time in 1999, again created major economic problems for transportation, businesses, and schools. Who in Chicago can forget the 40 inches of snow that fell in the first two weeks of 1979? The lack of snow removal from the streets of the city became the main focal point for Jane Bryne's successful mayoral campaign when she defeated incumbent Michael Bilandik and was swept into office under an avalanche of popular support. During the recent winter season of 2004-05, the Chicago area was twice hit with nearly a foot of snow. Of course, things could easily be worse. Just ask any residents of Boston or adjacent coastal areas of Massachusetts, buried under 2-3 feet of the white stuff in the Blizzard of 2005 on January 22-23, 2005! It is indeed fascinating to examine this detailed series of significant storms and often notable climate events that have occurred in the last century. This section represents the high point of the Climate Atlas of Illinois.

The U. S. Weather Bureau (now the National Weather Service) has been collecting weather data for more than 100 years. In Illinois, the establishment of the Illinois State Water Survey (ISWS) has enabled detailed information of the weather and climate in the state to be recorded and analyzed over an intensive 50-year period of time. In point of fact, "more data and information exists about the climate of Illinois than about any other area in the world" (Chapter 1, Page 6). Utilizing more than 100 years of collective experiences in weather and climate service, scientists from the ISWS (Stanley Chagnon, James Angel, Kenneth Kunkel, and Christopher Lehman) have published a definitive atlas on the climate of Illinois.

In addition to the considerable expertise of the authors, the atlas was able to fully utilize the wide-ranging amount of long-term data collected on the climate of Illinois. Three definitive aspects stand out. The scientific affiliation with the ISWS proves to be critically important. The survey operated 13 dense networks, for time periods ranging from 5 to 20 years, to obtain detailed precipitation and storm data for different areas across the state. Secondly, the ISWS has conducted a number of intensive studies (since 1954) focusing on all aspects of the state's climate. Fifty years of detailed research are represented in the atlas as a direct result. Finally, the survey established a statewide network of 18 recording stations, measuring temperature, precipitation, solar radiation, winds, soil moisture and soil temperature. This systematic climate data set provides a detailed and unique record which has been in operation for more than 20 years at this point.

The lead author, senior scientist and Chief Emeritus at the Water Survey, Stan Chagnon, has served both as the Illinois State Climatologist (office established at the ISWS in 1954) and director of the Midwestern Regional Climate Center (established in 1982). Co-author Jim Angel is the current State Climatologist while Ken Kunkel served previously as MRCC director. Christopher Lehmann, on staff with the National Atmospheric Deposition Program (part of the ISWS), brings expertise on air quality. Needless to say, the authors have brought their extensive backgrounds, and wealth of experience, together to

produce a detailed atlas that focuses on climatic conditions experienced during the 20th Century in Illinois.

The Climate Atlas of Illinois is divided into ten chapters. The initial introductory chapter provides an overview of the climate of Illinois, covering climatic controls and taking a look at the historical record as well. Chapters 2 and 3 are devoted to the fundamental aspects of climate, temperature and precipitation. Chapter 4 examines the statewide energy budget, particularly radiation, cloud cover, and winds. The specialized local-regional effects of Lake Michigan, topography, and human activity on climate conditions are discussed in detail in Chapter 5. Air quality is the focus of another human-induced climate concern in Chapter 6. Climate extremes (such as droughts) and all types of storms (rain-, hail-, thunder-, etc.) are treated in Chapter 7. Chapter 8 (my personal favorite) covers outstanding weather and climate events of the 20th Century. See how many you can remember! Chapter 9 deals with synoptic climatology - an examination of the frontal systems and air masses that control weather and climate conditions around the state. The final chapter (10) looks into climate issues of recent and potentially future concerns, including global warming, El Nino/La Nina, and climatic change. The atlas also contains an extensive bibliography, glossary, and two appendices. The first appendix describes weather instruments, climate statistics, and terminology. Appendix B contains climatological data summaries for 11 locations in Illinois. The atlas checks in at more than 300 total pages and contains extensive photographs and figures, along with a number of useful data tables. This publication is first class of high quality printed on glossy paper. Many of the photographs are in color; all are sharp, clear, and well suited in illustrating important points described in the writing. Graphics are also worthy of praise, well designed to highlight textual discussions, especially those illustrations which use color tones, which make them very easy to read.

Why develop a climate atlas of Illinois? Who is this volume intended for? The authors recognized that "climate is critically important to the state's economy, environmental conditions, and human health" (Chapter 1, Page 2). Climate conditions such as weather extremes and storms exert notable impacts on agricultural activities, businesses, economic conditions, transportation, and human health and safety. The atlas is a most welcome treatise intended for a wide variety of users, ranging from scientists and educators to agricultural and economic interests to the general public. Anyone who either uses climatic data, or simply has an abiding interest in weather, will no doubt find the atlas to be informative as well as helpful.

Although the atlas is indeed well written and informative, there are areas for improvement. Most of these are inherent to the nature of climatic data. When were the data used in analyses collected? In some cases, it appears that recent data are lacking, most noticeably in the chapter on severe storms. For example, many of the maps and graphs depicting tornado statistics only extend through 1969. Information about hailstorms are based on data through 1980, while snow and ice storms only cover the period up to 1960. The oldest climatic data set is that for windstorms, good through 1948. These examples point out difficulties due to limitations found in existing data sets, and suggest a need for updated studies. When working with climate data, there will always be areas of improvement, a future research topic to be investigated, or additional work to include the most recent developments in the data set. Also, the atlas lacks a comprehensive index, which would

be quite useful to users unfamiliar with climate data and anyone interested in a particular subject.

Fortunately, the drawbacks are relatively minor, and certainly do not detract from the overall usefulness of this excellent work. As a meteorologist/climatologist at Western Illinois University, I welcome the production of the Climate Atlas of Illinois. The authors were indeed able to combine their own wealth of knowledge with extensive sets of wide-ranging climatic data to produce an extremely detailed analysis of climatic conditions in Illinois. The atlas is very easy to read and follow, and abundantly illustrated. I highly recommend this book to anyone fascinated (as I am) with the highly volatile but always interesting weather and climate found in the state.

Reviewer: Dr. Thomas B. Williams, Associate Professor, Department of Geography, Western Illinois University, Macomb, IL 61255

BOOK REVIEW 2006 - #3

Horn, Dennis and Tavia Cathcart. Wildflowers of Tennessee, the Ohio Valley, and the Southern Appalachians. 2005. 496 pages; flower color key; selected dichotomous keys; colored photographs; line drawings; descriptions; illustrated glossary; references; index of Latin and common names. Lone Pine Publishing, Auburn, Washington. Soft Cover. 5½ x 8½ inches. ISBN 1-55105-428-0. Price: US $22.95. Available from Lone Pine Publishing, 1808 B Street NW, Suite 140, Auburn, WA 98001

Dennis Horn and Tavia Cathcart with contributions from Thomas Hemmerly and David Duhl, developed a splendid and well-designed wildflower guide. It begins with 300 flower-images, arranged by color, to help the reader to initially identify species. From here, the user is directed to more information about the species within its genus and family. Next, an introduction explains the guide, outlines the natural regions of Tennessee, and discusses the indigenous people, ethnobotany, and conservation activities within the state.

The bulk of the book covers more than 1200 species; over 800 are described and illustrated. These are arranged in groupings of related genera or families, separated by color banding along the top of each page. Lilies and other monocots are near the end of the guide, including a few distinctive sedges and grasses. The book ends with a glossary, references and an index.

The individual descriptions (two per page) are clearly organized with bold-faced sections. Habitat, range, and short statements regarding similar species are provided. The notes often include unusual features of the plants, the origin of their names, and information regarding their usefulness to Native Americans and early settlers. Descriptions are accompanied by photographs, and these are uniformly excellent. Whether close-ups of flowers and inflorescences, or more distant views of the entire plant, the color photographs provide the reader clear and informative images. Line drawings supplement keys to genera within larger families, and accompany the glossary. All told, this is a richly informative guide.

Though centered on Tennessee, the guide covers a large area ranging from southwestern Pennsylvania, western Virginia and the Carolinas to the northern parts of Georgia, Alabama and Mississippi, and westward to northeastern Arkansas and southeastern Missouri. The southern two-thirds of Illinois, Indiana and Ohio are also covered, making the guide useful for exploring much of our own state.

By having small images arranged by flower color in the front, with descriptions and larger photographs arranged by family groupings, this guide is useful to both beginners and to those already acquainted with plant families. An excellent glossary and the informative notes are important elements of the book. Considering the quality of the photographs and the wealth of information, this guide is a real bargain for anyone visiting the southern Appalachians and surrounding areas.

Reviewer: William Burger, Curator Emeritus, Department of Botany, The Field Museum, 1400 South Lake Shore Drive, Chicago, IL 60605

2006 Annual Meeting Student Awards

Cell, Molecular, and Developmental Biology Division – Paper Presentations

KATARZYNA KONIOR
University of Illinois – Chicago
The Localization of *Vorticella convallaria* Centrins to Distinct Compartments within the Contractile Organelle

ANDREW E. PRENDERGAST
Knox College
An Investigation of the Subcellular Distribution of Intersectin in *Xenopus lavevis*

Cell, Molecular, and Developmental Biology Division – Poster Presentations

DUSTIN C. HANCKS
Southern Illinois University – Edwardsville
Hybridization Between *Fundulus olivaceus* and *F. notatus* Assessed Using Single Nucleotide Diagnostic Markers

MARCIA MYRTHIL
Chicago State University
Dictyostelium Cells with GFP-Tabbed Hirano Bodies Grow More Slowly than Wild Type

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CHANCE YEOMAN
Western Illinois University
The Traveling Salesperson Problem with Time Windows

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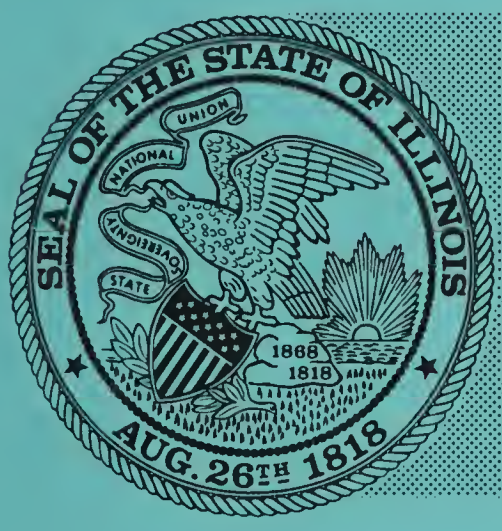

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Errata

The paper by Burke & Stratton on Rugose Corals of the Livingston Limestone Member which appeared in Issue #1&2 of *Transactions* volume 98 (2005) was originally printed with an incorrect figure caption for page 157. A corrected page is printed, with the original paper numbering following this notice for easy insertion into printed volumes.

Figure 4. Images of study samples. Scale is in centimeters. (1.) Specimen 072, *Geyerophyllum* sp. cf. *G. broilii*, external view. (2.) 072, sp. cf. *G. broilii*, transverse section, note sporadic lonsdaleoid dissepiments. (3.) 072, sp. cf. *G. broilii*, longitudinal section. (4.) Specimen 100, sp. cf. *G. broilii*, highly flaring specimen. (5.) 100, sp. cf. *G. broilii*, oblique longitudinal section.

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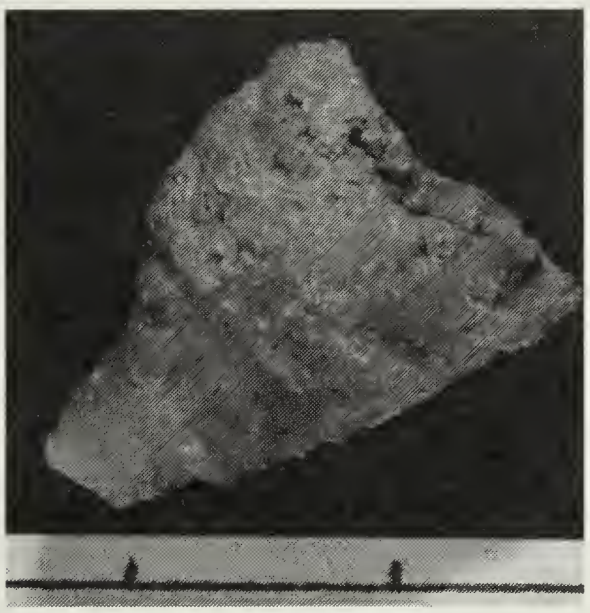

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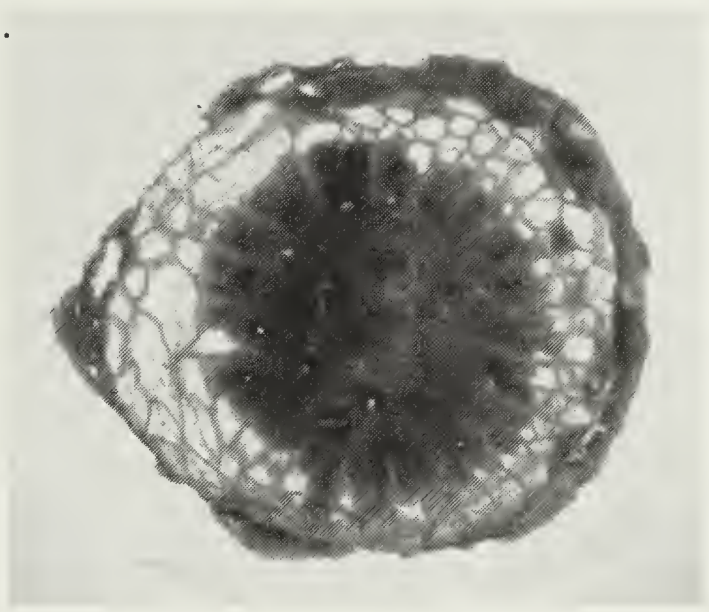

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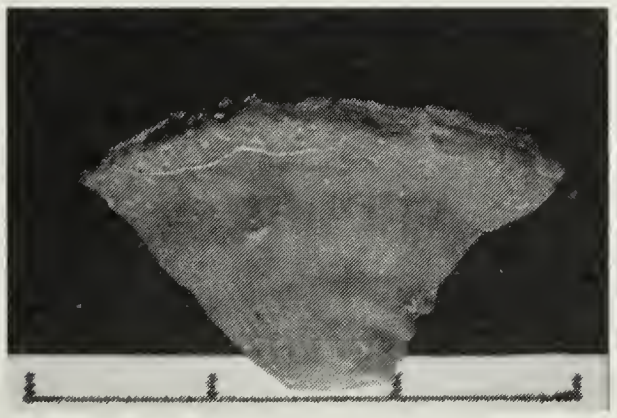

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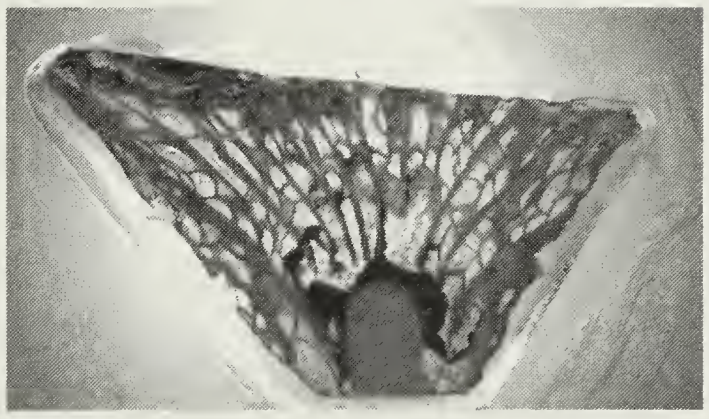

Issue 3&4 of 2006 continues with the article by Getz.

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Use of National Weather Station Records in Field Studies of Forest Species of Small Mammals

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ABSTRACT

I tested the hypothesis that temperatures from a National Weather Service (NWS) station were comparable to those 20 cm above the surface, the stratum utilized by most forest species of small mammals, of lowland swamp and upland hardwood forest habitats 35 km from the NWS station. Temperatures at the NWS station, whether every two hours during the day, mean daily, mean daily maximum and minimum, or monthly maximum and minimum, were similar to those in both the swamp and upland sites. Such differences that did occur typically varied only 3-5° C, and most often 1-2° C, between the NWS station and the field sites. Daily maximum and minimum temperatures at the NWS station were positively correlated with those in both the swamp and upland sites at all seasons. Use of temperature records from the NWS station located in a rural exposure, even though distant from a field site, would be suitable in describing relative temperatures encountered by animals active on the forest floor or up onto lower trunks of trees.

INTRODUCTION

Analyses of data from field studies of small mammals frequently test effects of weather conditions on demographic variables such as survival, activity, dispersal, and reproduction (Madison, 1985; Kriegsfeld et al., 2000; Jackson et al., 2001). Time constraints and limited resources often prohibit monitoring of temperatures within the study site itself, even though such technology is readily available (e.g., I-buttons, Dallas Semiconductor). Analyses of data from some studies may suggest importance of factors that were not a part of the original protocol, or long-term studies may require retrospective analysis of temperature conditions. In these cases researchers must obtain temperature data from elsewhere, typically from existing National Weather (NWS) stations, which are often located far from the study site (Jackson et al., 2001; Brady and Slade, 2004; Selås, 2006). In addition to variation in general temperature regimes between the study site and the NWS station, potential bias results from the standard positioning of recording instruments 1 m above the surface at NWS stations. Thus, reliability of such data in describing conditions at the actual study site is questionable. Elsewhere (Getz, 2005) I show that temperature records from a NWS station located 6.6 km from a study site did not accurately

describe conditions encountered by the prairie vole (*Microtus ochrogaster*), meadow vole (*M. pennsylvanicus*), and short-tailed shrew (*Blarina brevicauda*). These small mammals occupied enclosed runways at the soil surface under a dense layer of vegetative and detritus cover.

During the course of a study of the red-backed vole, *Clethrionomys gapperi*, (Miller and Getz, 1972) temperature data were recorded at the level of activity in the habitat occupied by each species. These two species were active on the open forest floor and up on small fallen logs and tree stumps (both species) as well as up on trunks of trees (*P. leucopus*). Temperatures encountered by such species, when active, would not be subject to moderation by dense vegetative and detritus cover as were the voles and short-tailed shrew in the above study (Getz 2005). I here test the hypothesis that temperatures recorded at a distant NWS station are representative of those 20 cm above the surface of lowland swamp and upland forest sites 35 km from the NWS station.

METHODS AND MATERIALS

Study site

The field study site was located in a cedar swamp and an adjacent upland deciduous forest, 5 km NW of Storrs, Connecticut. The NWS station was located in a "rural exposure" site (Brumbach, 1965) at Bradley International Airport, 35 km NW of the field sites.

The two study sites were described in detail by Miller and Getz (1972). Vegetation of the swamp was composed of a 50-75% crown coverage of hemlock (*Tsuga canadensis*), southern white cedar (*Chamaecyparis thyroids*), yellow birch (*Betula lutea*), and red maple (*Acer rubrum*). An open (44% coverage) shrub stratum included pepper bush (*Clethra alnifolia*), mountain laurel (*Kalmia latifolia*), mountain holly (*Nemopanthus mucronatus*), ilex (*Ilex* sp.), and high bush bluebberry *(Vaccinium* sp.). In places there was a dense (100%) forb stratum of skunk cabbage (*Symplocarpus foetidus*) and cinnamon fern (*Osmunda cinnamomea*), but the overall average forb coverage was 31%. The surface was covered by a 5-10 cm layer of twigs and leaves.

The upland vegetation consisted of a second-growth stand of red and white oaks (*Quercus rubra* and *Q. alba*), with scattered red maple and hemlock. The trees were 15-18 m tall and had an average crown coverage of 75%. There was a sparse (5-15% coverage) shrub stratum of oaks, red maple, chestnut (*Castanea dentata*), maple-leaf viburnum (*Viburnum acerifolium*), and low bush blueberries (*Vaccinium* sp.). Forbs were very sparse (8% coverage). A well-developed 15-20 cm leaf layer covered the forest floor.

Temperature records

Eight temperature stations, each, (five Bristol and three Taylor recording thermographs) were placed in the swamp and upland forest (Miller and Getz, 1972). The stations were located within a 50-m radius at each site. So as to describe vegetative cover conditions specifically at the temperature stations, vegetative coverage within a 15 m radius around each station was visually estimated and means for the stations at each site calculated for the tree crown >15 m, shrubs, >1 m, and forbs, <1 m (Swamp: trees, 69.4% [deciduous, 30.6%; evergreen, 38.8%]; shrubs, 32.5%; forbs, 56.9%. Uplands: trees, 76.3% [deciduous, 69.4%; evergreen, 6.9%]; shrubs, 20.6%; forbs, 26.9%).

The instruments were covered by aluminum painted tent-shaped 50 cm wide plywood shelters on 20 cm high legs that allowed for free circulation of air over the sensitive elements of the instruments. The temperature-sensitive elements of the instruments were positioned 20 cm above the surface. This allowed for recording temperatures typical of those encountered by the small mammals during their periods of activity. Ink pens traced the temperatures on paper charts. The charts were changed weekly and the ink pens filled. Temperature sensors were calibrated every few months with glass mercury thermometers. The temperature stations were maintained from June 1963-June 1967.

Data analysis

Temperature data were compiled from the recorder charts at 2-hour intervals, beginning at midnight (00 hours). Mean temperatures for the swamp and upland were analyzed for 10-day periods during winter (8-17 January 1966), spring (2-11 May 1964), summer (23 July-1 August 1966), and autumn (23 October-1 November 1964). These dates represented periods of greatest continuous low winter temperatures and high summer temperatures and of typically moderate spring and autumn temperatures recorded during the study. Daily maximum and minimum temperatures for the swamp and upland were compiled for all years for the months of January-February (winter), April-May (spring), July-August (summer), and October-November (autumn). These comparisons were restricted to the two months most representative of each season. Monthly mean maximum and minimum temperature were calculated for all months, June 1963-June 1967. Equivalent compilations and means were obtained for the same dates from records of the NWS station. Significance of differences between the two habitats and the NWS station were determined by use of one-way ANOVA, followed by Tukey's honestly significant difference (HSD) post-hoc multiple comparison tests (Zar, 1999). Correlation analyses of temperatures at the NWS station and the field sites utilized Pearson's *r* (Zar 1999).

RESULTS

Daily temperatures were generally higher at the NWS station than in either the swamp or upland sites; the differences of the total 24-hr and day-time temperatures were significant only during summer (Fig. 1, Table 1). Differences were greatest (3-4° C) for about four hours (0800-1200) during the morning (Fig. 1); only those during the summer were significant ($F = 5.322$; df = 2,6; P = 0.05). When only night-time temperatures were considered, temperatures at the NWS station were significantly higher than those in the upland during winter and the swamp during summer and autumn (Table 1).

Although night-time differences for all seasons and day-time differences during summer were significant, actual daily maximum and minimum temperatures in both the swamp and upland sites differed little (usually <2° C) from those at the NWS station (Table 2). Greatest differences occurred during the day in summer (Table 1). For all four seasons there was a significant correlation (P <0.01; Pearson's *r* test) of both daily maximum (Swamp: winter, $r = 0.77$; spring, $r = 0.70$; summer, $r = 0.90$; autumn, $r = 0.75$. Upland: winter, $r = 0.89$; spring, $r = 0.97$; summer, $r = 0.52$; autumn, $r = 0.98$) and minimum temperatures (Swamp: winter, $r = 0.76$; spring, $r = 0.87$; summer, $r = 0.82$; autumn, $r = 0.88$. Upland: winter, $r = 0.82$; spring, $r = 0.48$; summer, $r = 0.88$; autumn, $r = 0.95$) at the NWS station and both field sites. When all months were compared, monthly maxi-

mum and minimum temperatures at the NWS station did not differ significantly from those in either the swamp or upland sites (Maximum temperatures: $F = 0.18$; df = 2,134; P = 0.84. Minimum temperatures: $F = 1.00$; df = 2,136; P = 0.37).

DISCUSSION AND CONCLUSIONS

Even though the National Weather Service (NWS) station was located 35 km from the study sites, temperatures there were very close to those in both the swamp and upland sites. Thus, the results of this study support the hypothesis that temperatures at a NWS station were representative of those 20 cm above the surface of sites 35 km from the NWS station. The few differences that were recorded were brief and usually of a magnitude of only 1-2° C; only the maximum temperatures in the swamp habitat during summer deviated from those at the (NWS) station by up to 6° C and then for only about four hours during the morning. Higher temperatures at the NWS station during the summer most likely result from the exposure of the NWS station to full sunlight, whereas the study sites were shaded by vegetation.

The Bradley Airport NWS station was located in a rural exposure, with minimal urban climate effects (Brumbach, 1965). The predominately hilly terrain for northern Connecticut, in which this study was conducted, presents the potential for differences in local climate. Comparison of records from 1931-1960 for nine NWS stations located at distances of 10-160 km from each other showed that such differences were relatively minor (greatest differences: mean monthly maximum temperatures, 1.9° C; mean monthly minimum temperatures, 2.7° C; mean monthly temperatures, 2.2° C; Brumbach, 1965).

I conclude therefore that usage of temperature data from a distant weather station, in this case the Bradley Airport NWS station 35 km away, would be appropriate for describing temperatures encountered by small mammals when active on or above the surface floor of both lowland swamps or upland forests. Whereas actual temperatures in a forested site may deviate slightly from those recorded at the weather station, the latter do provide a good picture of temperature patterns at the remote sites. NWS station data should be obtained from stations located in rural exposures so as to reduce bias from urban climate effects (Brumbach, 1965). Professionalism of the person(s) maintaining the NWS service weather stations should also be taken into account in respect to reliability of temperature records. Although the comparisons in this study related to conditions encountered by small mammals, the same conclusions apply to any small animal living on the forest floor or active on fallen logs and the lower trunks of trees.

ACKNOWLEDGEMENTS

The study was supported by NSF grants G-22553 and GB-2242 and by funds from the University of Connecticut Research Board. D. Miller, L. Chichester, and D. Lovejoy assisted with the field work. K. Chiappeta and M. Novak compiled the temperature data. A contribution from the Biological Sciences Group, University of Connecticut.

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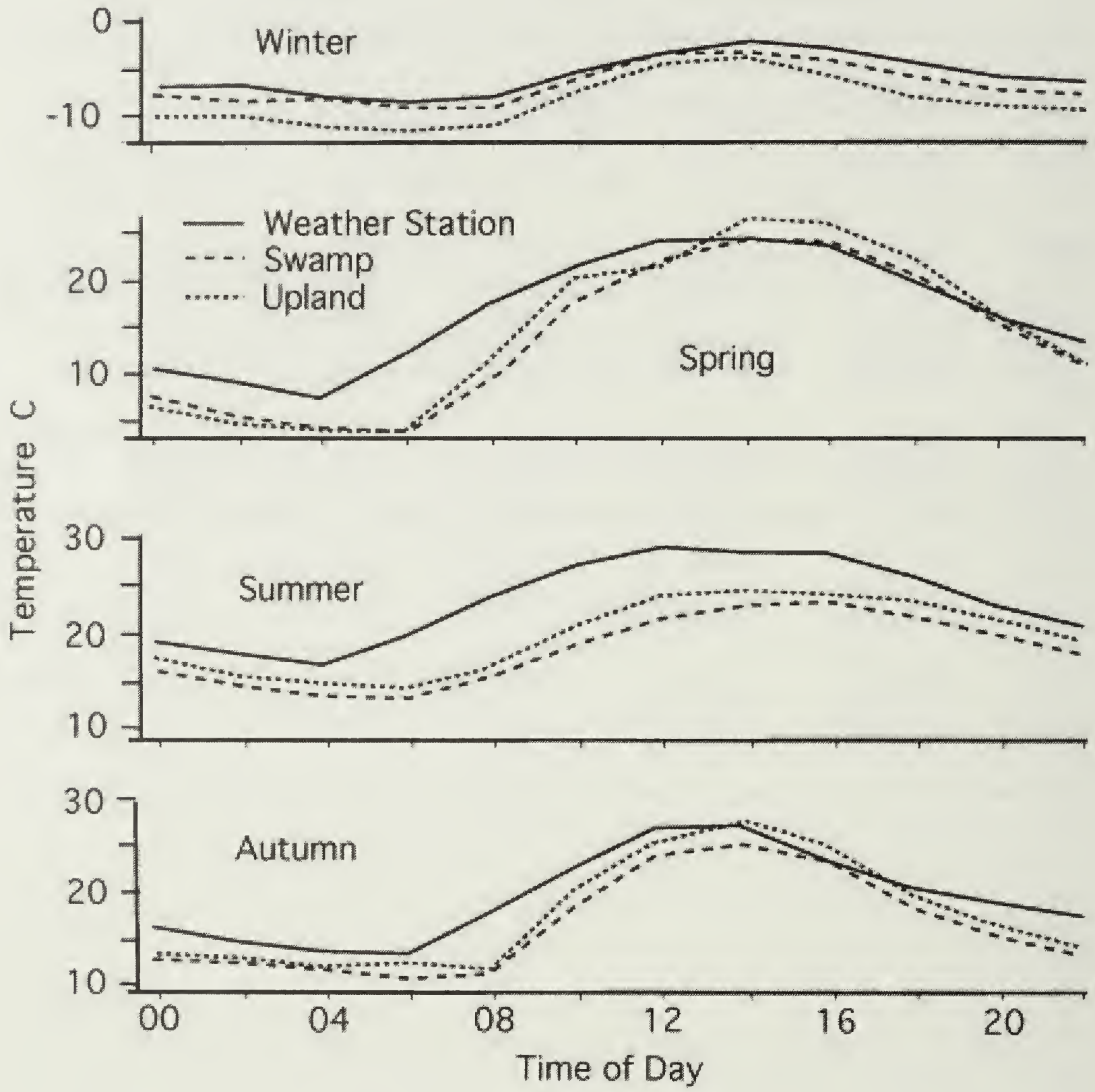
Table 1. Mean daily temperatures, (°C; compiled at 2-hr intervals) 20 cm above the surface in a swamp and adjacent upland forest, 5 km NW of Storrs, Connecticut and at a National Weather Service station (NWS) at Bradley International Airport, 35 km from the field sites. Data were analyzed for a 10-day period in respect to the entire 24-hr period, day-time (08-20 hrs), and night-time (22-06 hrs) during a very cold winter period (8-17 January 1966), a period of very high summer temperatures (23 July-1 August 1966) and periods of moderate temperatures during spring (2-11 May 1964) and autumn (23 October-1 November 1964). Field site values with an asterisk (*) differ from those at the NWS station at <0.05 (Tukey's HSD test).

Season	Time	Site			*F*; df	P
		NWS station	Swamp	Upland		
Winter	24 hrs	-6.1 ± 0.6	-7.1 ± 0.6	-7.5 ± 0.7	1.24; 2,33	0.30
	08-20	-5.8 ± 0.7	-6.0 ± 0.8	-6.0 ± 0.8	0.57; 2,18	0.58
	22-06	-7.7 ± 0.4	-8.5 ± 0.3	-9.5 ± 0.5*	5.78; 2,12	0.02
Spring	24 hrs	16.6 ± 1.2	13.8 ± 2.2	14.5 ± 2.5	0.46; 2,33	0.64
	08-20	21.0 ± 1.3	19.0 ± 2.0	20.6 ± 1.9	0.34; 2,18	0.72
	22-06	10.5 ± 1.1	6.4 ± 1.3	5.9 ± 1.3	4.14; 2,12	0.04
Summer	24 hrs	23.2 ± 1.3	18.2 ± 1.0*	19.6 ± 1.1*	5.13; 2,33	0.01
	08-20	26.4 ± 0.9	20.5 ± 1.0	22.1 ± 1.0	9.65; 2,18	<0.01
	22-06	18.8 ± 0.7	15.0 ± 0.8*	16.2 ± 0.9	5.60; 2,12	0.02
Autumn	24 hrs	9.7 ± 1.3	13.8 ± 2.2	14.5 ± 2.5	1.52; 2,33	0.23
	08-20	12.7 ± 1.5	9.7 ± 1.8	11.2 ± 12.0	0.68; 2,18	0.52
	22-06	5.6 ± 0.8	2.7 ± 0.4*	3.5 ± 0.4	7.05; 2,12	<0.01

Table 2. Mean daily maximum and minimum temperatures 20 cm above the surface of a swamp and adjacent upland forest, 5 km NW of Storrs, Connecticut and at a National Weather Service (NWS) station at Bradley International Airport, 35 km from the field sites (winter, January-February; spring, April-May; summer, July August; autumn, October-November). Field site values with an asterisk (*) differ from those at the NWS station at <.05 (Tukey's HSD test).

Season	Temperature	Site			*F*; df	P
		N. W. S.	Swamp	Upland		
Winter	Maximum	1.5 ± 0.3	1.5 ± 0.2	1.0 ± 0.3	1.13; 2,884	0.32
	Minimum	-8.1 ± 0.4	-6.7 ± 0.3*	-8.8 ± 0.3	11.84; 2,883	<0.01
Spring	Maximum	18.8 ± 0.4	18.1 ± 0.4	19.5 ± 0.4*	2.89; 2,912	0.06
	Minimum	5.0 ± 0.3	2.5 ± 0.3*	3.1 ± 0.2*	36.51; 2,910	<0.01
Summer	Maximum	29.1 ± 0.3	23.1 ± 0.2*	24.7 ± 0.3*	204.68; 2,741	<0.01
	Minimum	15.7 ± 0.2	13.0 ± 0.2*	14.0 ± 0.2*	31.04; 2,739	<0.01
Autumn	Maximum	16.2 ± 0.4	12.9 ± 0.4*	14.5 ± 0.4*	18.67; 2,668	<0.01
	Minimum	3.0 ± 0.3	0.5 ± 0.2*	1.0 ± 0.3*	18.26; 2,669	<0.01

Figure 1. Seasonal comparisons of average temperatures, compiled at 2-hr intervals for 10-day periods, in a cedar swamp and adjacent upland deciduous forest with those recorded at a National Weather Service station 35 kilometers away. For dates of records, see Table 1.



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Tropical Storms Reduced Drought in Illinois in 2005

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ABSTRACT

The passage of four tropical systems alleviated drought impacts, particularly in southern and central Illinois during the 2005 growing season. The four systems were Tropical Storm Arlene, and Hurricanes Dennis, Katrina, and Rita. Several circumstances make this situation significant for Illinois. The historical tropical cyclone records indicate that while an occasional tropical system passes through Illinois (26 years since 1851), 2005 was the first time for four such systems in one season. Timing of 4 to 6 weeks between tropical systems benefited agriculture while minimizing flooding. Tropical Storm Arlene and Hurricane Dennis also occurred relatively early in the growing season when critical moisture was needed. Aggregating the rainfall from these four events shows that they provided significant drought relief in southern and central Illinois during the 2005 growing season. Without those four systems, southern and central Illinois could have been in drought almost as severe as that in northern Illinois with 7- to 10-inch rainfall deficits instead of the observed 1- to 6-inch rainfall deficits.

INTRODUCTION

Beginning in March 2005, a severe drought developed in Illinois as significant rainfall deficits accumulated during the growing season. State-wide spring (March-May) rainfall was 5.42 inches below normal, and summer (June-August) rainfall was 2.87 inches below normal. The period of March-October was the fourth driest such period since state-wide records began in 1895 with only 19.69 inches of rain, 9.53 inches below normal. Precipitation deficits in northwestern Illinois, the area hardest hit by the drought, were on the order of 12 to 18 inches below normal at individual stations by the end of October. A more detailed account of the 2005 drought and its impacts can be found in Kunkel et al. (2006). One of the outstanding climatic aspects of the 2005 drought was the role of tropical storms in alleviating the drought across southern and central Illinois.

Tropical storms have been known to bring beneficial rains to drought-stricken areas, typically along the Gulf and East Coasts. Sugg (1968) documented nine such cases from 1928 to 1963, using the Palmer Drought Severity Index to identify areas in drought. The most significant example was the pair of hurricanes (Diane and Connie), only a week apart in 1955, which produced rains over 80,000 square miles that were considered to be in drought status along the East Coast. More recently, Hurricane Floyd produced heavy rainfall along the East Coast in September 1999, causing widespread flooding and

abruptly ending a drought emergency in New Jersey (Robinson, 2000). Larson et al. (2005) examined the climatology of land-falling tropical cyclones in the United States and Mexico, demonstrating that a significant portion of the mean annual precipitation along the Gulf and East Coasts comes from tropical cyclones. On average, a small contribution (less than 5 percent) extended as far north as extreme southern Illinois.

One of the outstanding features of the 2005 North Atlantic hurricane season was the record number of named storms (27) and three Saffir-Simpson category 5 storms (Shein 2006).This paper examines the four tropical storms (Arlene, Dennis, Katrina, and Rita) that passed through Illinois during the 2005 growing season. The precipitation pattern and other synoptic features of each storm are reviewed. The aggregated precipitation pattern and its impact on the 2005 drought are discussed.

DATA AND METHODOLOGY

Three data sources were used in this study. Gridded precipitation data came from the Midwestern Climate Information System (MICIS) system (Kunkel et al., 1990) of the Midwestern Regional Climate Center, based on data from the US cooperative observer network. Daily weather map series were obtained from the National Weather Service (2005). Tropical cyclone tracks from the Atlantic and Northeast Pacific Tropical Cyclone HURDAT dataset from the National Hurricane Center (described in Neumann et al. 1999) for the period 1851-2004. This last dataset contains hurricanes (sustained wind speeds in excess of 74 mph), tropical storms (sustained winds between 40 and 74 mph) and tropical depressions (sustained winds between 23 and 39 mph).

For the 2005 season, dates when the tropical systems passed through Illinois were determined. Rainfall amounts from those days then were accumulated separately from the rest of the growing season. Finally, maps of total rainfall amounts from all sources, the total rainfall from tropical storms, and the total rainfall without tropical storms were determined for the growing season. Historical counts of tropical cyclones passing through Illinois were determined by identifying systems that passed north of 35°N latitude and between 85° and 93°W longitude. These latitude and longitude criteria were determined based on the tracks of the four storm systems in 2005.

Reconstructing the actual rainfall contribution of a storm system is challenging when using daily data. Because the data are a combination of morning, afternoon, and midnight observations from different stations, it was decided to include data not only from the dates when the tropical system passed through Illinois but also from the day after to include any morning observations after the event. In many cases, tropical systems moving through the Midwest can cover areas hundreds of miles wide and interact with existing synoptic features, such as a passing cold front. As a result, it is not always possible to identify rainfall exclusively from tropical systems.

RESULTS AND DISCUSSION

There were four tropical systems of interest in 2005. Rainfall from those storms fell in Illinois on June 11-13 (Tropical Storm Arlene), on July 11-13 (Hurricane Dennis), on August 30-31 (Hurricane Katrina), and on September 25-26 (Hurricane Rita). Figure 1

shows their tracks. All four struck the Gulf Coast and then moved up the Mississippi and Ohio River valleys. Examination of previous records reveals that one or more tropical storms do occasionally pass through Illinois: two storms each in 8 years (1901, 1906, 1916, 1948, 1949, 1950, 1960, and 1985) and one storm each year in 18 years since 1851 (1879, 1891,1893, 1898,1909, 1912, 1923, 1933, 1940, 1942, 1947, 1953, 1955, 1970, 1986, 1988, 2001, and 2002). The 1940s, the most active decade, had seven storms passing through Illinois. Two decades, the 1950s and 1980s, had four storms in each decade. Only in 2005 were four storms per year reported, the maximum seen in the historical record, a rarity made even more impressive by a total of just three tropical systems passing through Illinois between 1956 and 1984.

There are several important features regarding the timing of the four 2005 events. The four events were spaced 4 to 6 weeks apart during the growing season, thus benefiting crop growth and minimizing the threat from flooding. Tropical Storm Arlene and Hurricane Dennis occurred relatively early in the tropical storm season and arrived at critical times in the growing season for Illinois. For example, Hurricane Dennis arrived in mid-July just as many cornfields were beginning the silking and tasseling stage when precipitation is particularly critical.

The first tropical system to pass through Illinois in the 2005 growing season was Tropical Storm Arlene in June 2005. Like the other three systems affecting Illinois that season, the storm moved up through the Gulf of Mexico, following first the Mississippi River valley and then the Ohio River valley. As Figure 2 shows, the rain in Illinois was confined largely to the southern part of the state along the Wabash River valley. Amounts of 1 to 2 inches were common in this area with a peak at Mount Carmel of 4.28 inches. The surface weather map for June 12, 2005, showed that a cold front located to the west in Missouri and Iowa did not appear to interact with the passing tropical system. Therefore, it can be concluded that the rainfall on June 11-13 was almost exclusively from Tropical Storm Arlene.

The second tropical system, a category 4 hurricane, was Hurricane Dennis in July 2005. After causing damage along the Gulf Coast, it moved inland and weakened to a tropical depression before reaching Illinois. The surface weather map for July 12, 2005, shows no pre-existing synoptic features in the Midwest to steer this storm. As a result, the storm meandered over Illinois for several days (July 11-13) before dissipating. Once again, timely rains greater than 1.5 inches were produced over southern Illinois (Figure 3), including a peak of 5.03 inches at Cairo. Even central Illinois received up 2 inches of much needed rain. As with Tropical Storm Arlene, little or no rain fell in northern Illinois.

The third tropical system over Illinois was Hurricane Katrina in August 2005. While causing massive damage and more than 1800 deaths along the Gulf Coast, the system brought rain and no severe weather to Illinois. Of the four tropical systems, this one brought the least rain to Illinois and that rainfall was confined largely to southeastern Illinois. Amounts of about one inch were common in that area while southwestern Illinois and central Illinois received about 0.25 inches, while northern Illinois received none (Figure 4). The surface weather map for August 30, 2005, indicated no other rain-pro-

ducing features in the area so all rainfall on August 30-31 in Illinois was attributed to Hurricane Katrina.

The final tropical storm to affect Illinois was Hurricane Rita in September 2005. This storm produced widespread rains across the state (Figure 5) with typical amounts of 0.5 to 1.5 inches and up to 2.66 inches at Lebanon (east of St. Louis, Missouri) on September 25-26. Unlike prior storms, this one had benefits for northern Illinois. The surface weather map for September 25, 2005, indicated the presence of a rain-producing cold front that later moved through northern Illinois. Hurricane Rita may have interacted with this synoptic feature to enhance the rainfall across Illinois and is the only one of the four tropical systems from which some rainfall on chosen dates may have been from other synoptic-scale features.

During the 2005 growing season, Illinois experienced an intense drought that began in the spring with the most serious rainfall departures in north-central Illinois. Rainfall departures of 8 to 11 inches from the 1971-2000 mean for March-September occurred across much of northern and west-central Illinois (Figure 6). Rainfall departures in southern Illinois were less severe. In fact, extreme southern Illinois experienced near-normal rainfall during this time.

What was the total rainfall contribution of those four tropical systems? Figure 7 shows that the June-September aggregate rainfall ranged from 3 to 8 inches in southern Illinois, 1 to 3 inches in central Illinois, and less than an inch to 2 inches in northern Illinois. Clearly, the timely rains from these four storms reduced drought severity in the southern half of the state and in some areas even eliminated drought completely.

Figure 8 shows the March-September rainfall departures minus the rainfall of the four tropical systems. Rainfall departures would have been slightly more severe in northern Illinois, which already had the most impacts. The biggest impact could have been in central and southern Illinois, which experienced drought conditions almost as severe as those in northern Illinois with rainfall deficits since March 2005 of 7 to 10 inches. Such deficits would have had a significant impact on crop production, pastures, stream flow, water levels in small lake, and groundwater.

Kunkel at al. (2006) noted that the precipitation deficits observed in Illinois were consistent with weaker-than-normal low-level flow from the Gulf of Mexico and Atlantic Ocean moisture sources. In turn, this weaker-than-normal flow may have been the result of warmer-than-normal sea surface temperatures (SST) in the Atlantic and Gulf of Mexico. At the same time, the warmer SSTs are believed to be one of several factors contributing to a more active tropical storm season in 2005 (Shein 2006). The end result is that the warmer SSTs in 2005 may have had a hand in both causing and alleviating drought in Illinois in 2005.

There is considerable debate in the scientific community about the significance of the 2005 Atlantic hurricane season as it relates to climate change (e.g. Anthes et al. 2006 and Pielke et al. 2006). While storms were well-documented after they made landfall since the mid-1800s, their frequency and strength over oceans were improved by aircraft observations from the 1940s onward, and greatly improved by satellite observations from

the 1970s onward. This makes it very difficult to identify long-term trends in the database. In addition, there is substantial natural variability in the historical records, including an apparent 20-40 year "Atlantic Multi-decadal Oscillation," that makes it harder to identify a global warming signal. The challenges and current state of science are accurately summarized in a recent statement by the World Meteorological Organization's Tropical Meteorology Research Program Panel (McBride et al. 2006).

CONCLUSIONS

Unprecedented passage of four tropical systems (Tropical Storm Arlene, and Hurricanes Dennis, Katrina, and Rita) alleviated drought impacts during the 2005 growing season, particularly in southern and central Illinois. Several circumstances make this situation significant from a climatological perspective. The historical tropical cyclone records indicates that while an occasional tropical system passes through Illinois (26 years since 1851), 2005 was the first time for four such systems in one season. Timing of 4 to 6 weeks between events benefited agriculture while minimizing flooding. Tropical Storm Arlene and Hurricane Dennis also occurred relatively early in the growing season when critical moisture was needed.

By aggregating the rainfall from these four events, it was shown that they provided significant drought relief to southern and central Illinois during the growing season. Aggregated rainfall amounts ranged from nearly 8 inches in far southern Illinois to less than an inch in northern Illinois. Without those four systems central and southern Illinois could have been in drought almost as severe as that in northern Illinois with 7- to 10-inch rainfall deficits instead of the observed 1- to 6-inch rainfall deficits.

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Figure 1. The storm tracks of all four tropical storms that passed through Illinois in 2005. They are, in chronological order: 1) Tropical Storm Arlene (X), 2) Hurricane Dennis (O), 3) Hurricane Katrina (*), and 4) Hurricane Rita (+).

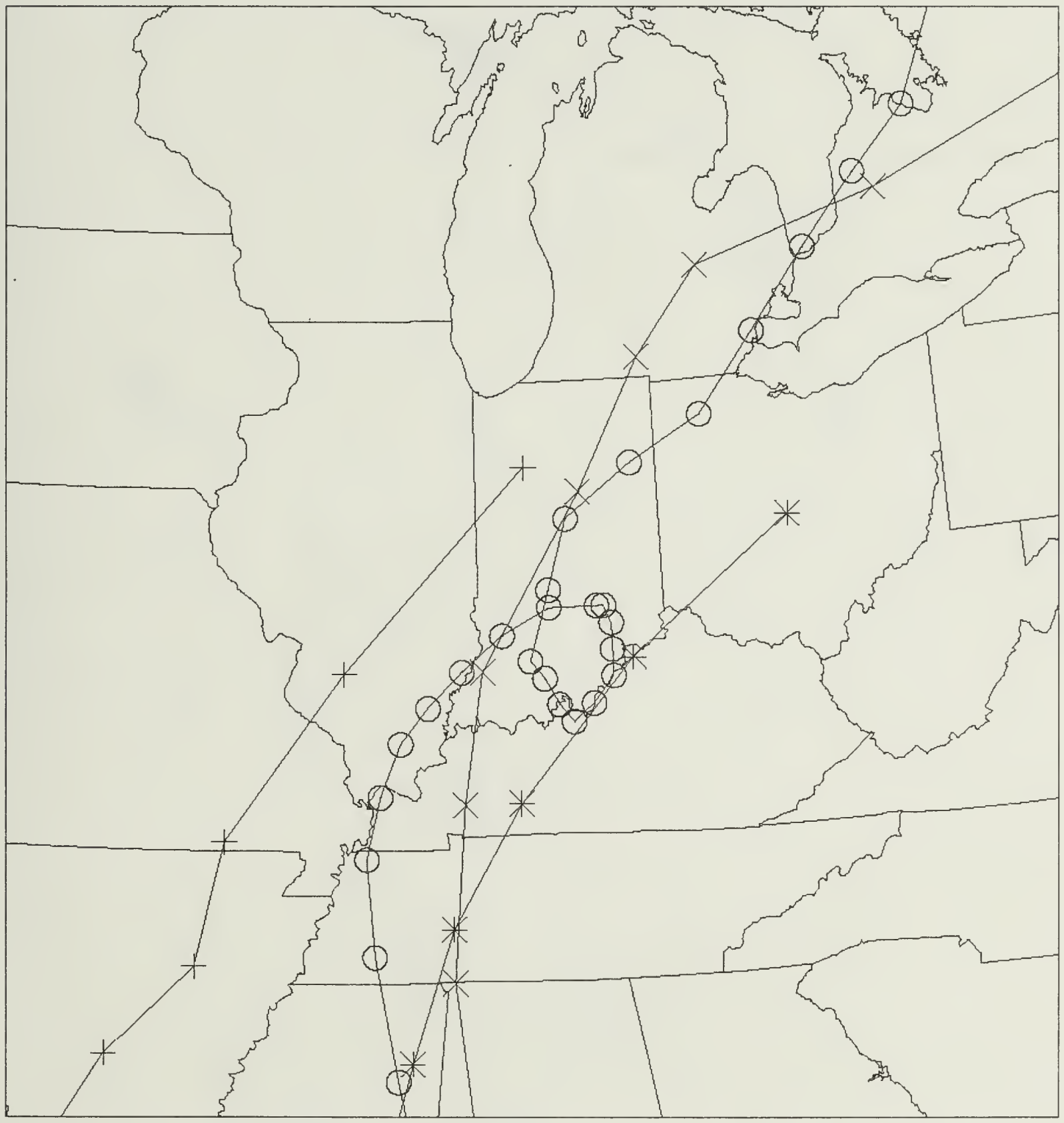


Figure 2. Rainfall (inches) from Tropical Storm Arlene.

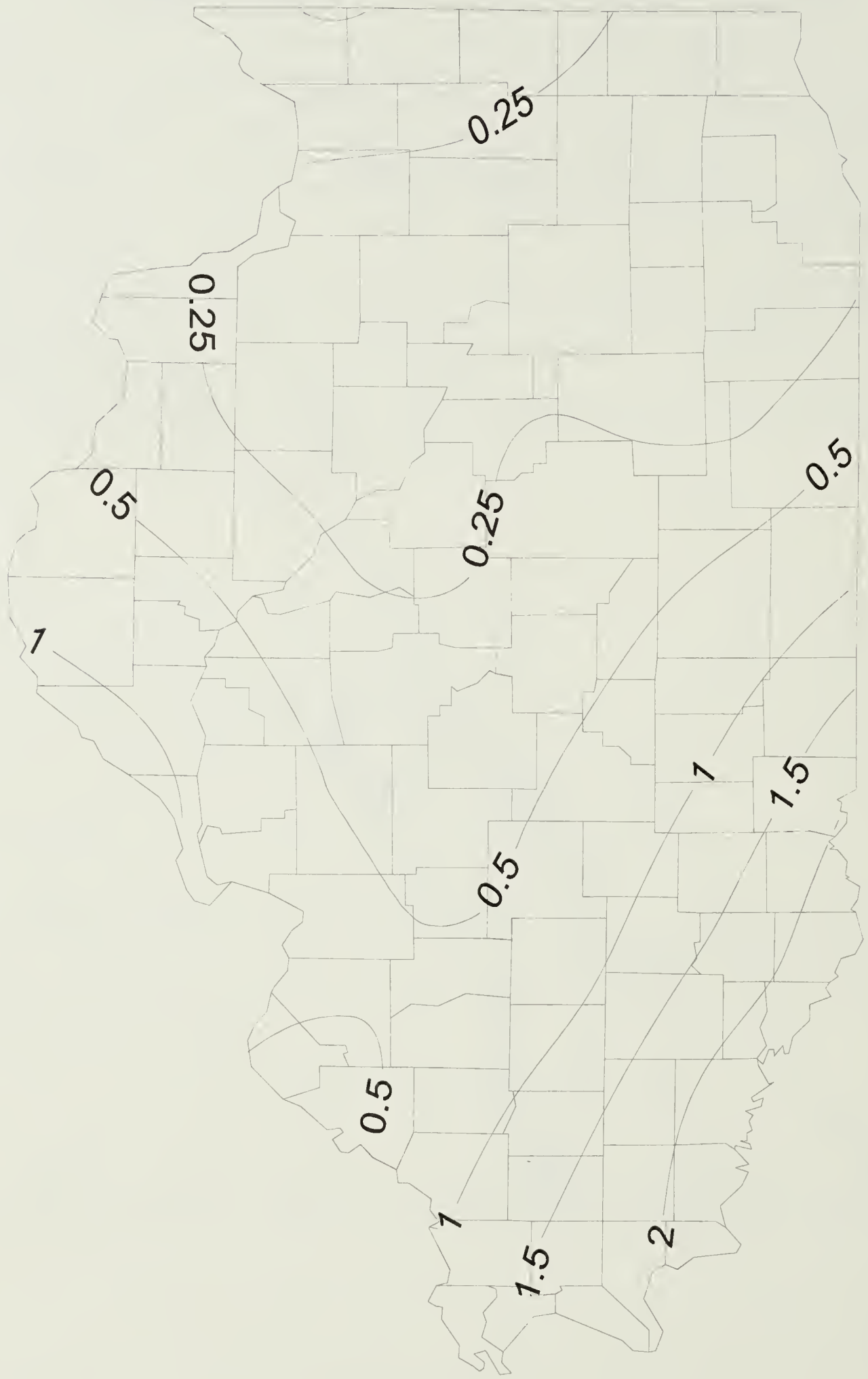


Figure 3. Rainfall (inches) from Hurricane Dennis.

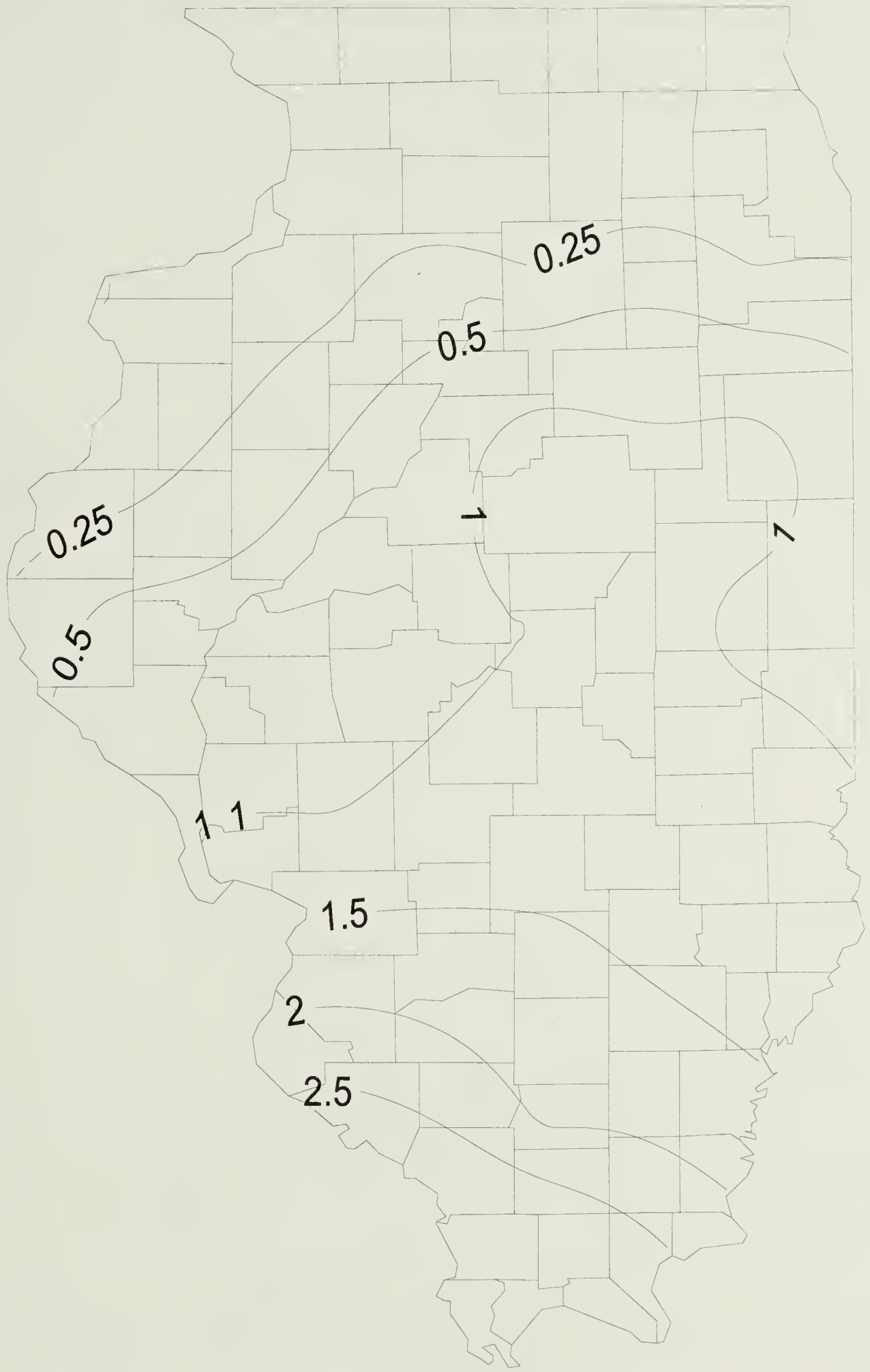


Figure 4. Rainfall (inches) from Hurricane Katrina.

Figure 5. Rainfall (inches) from Hurricane Rita.

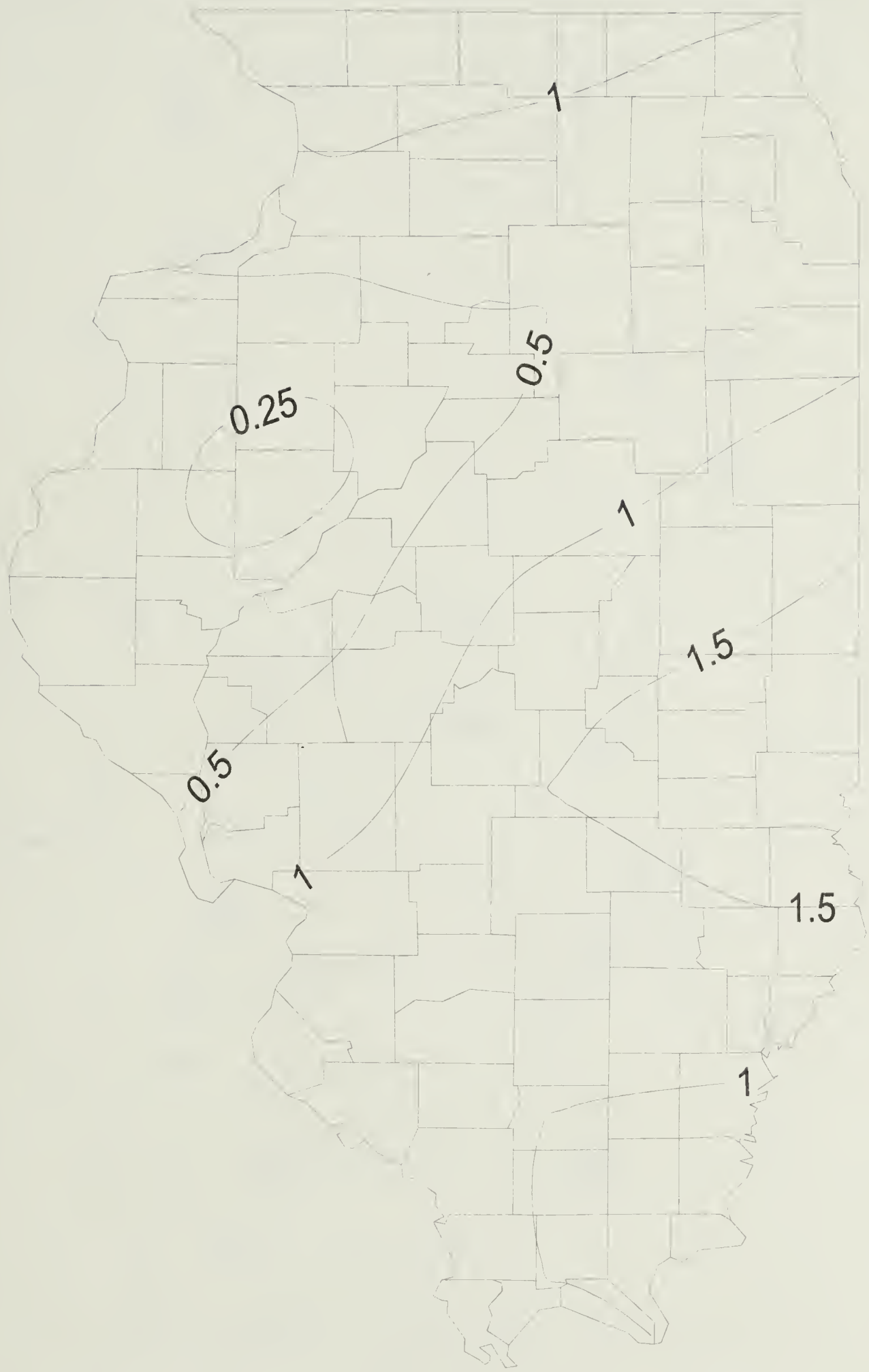


Figure 6. The March-September rainfall (inches), expressed as a departure from normal (1971-2000).

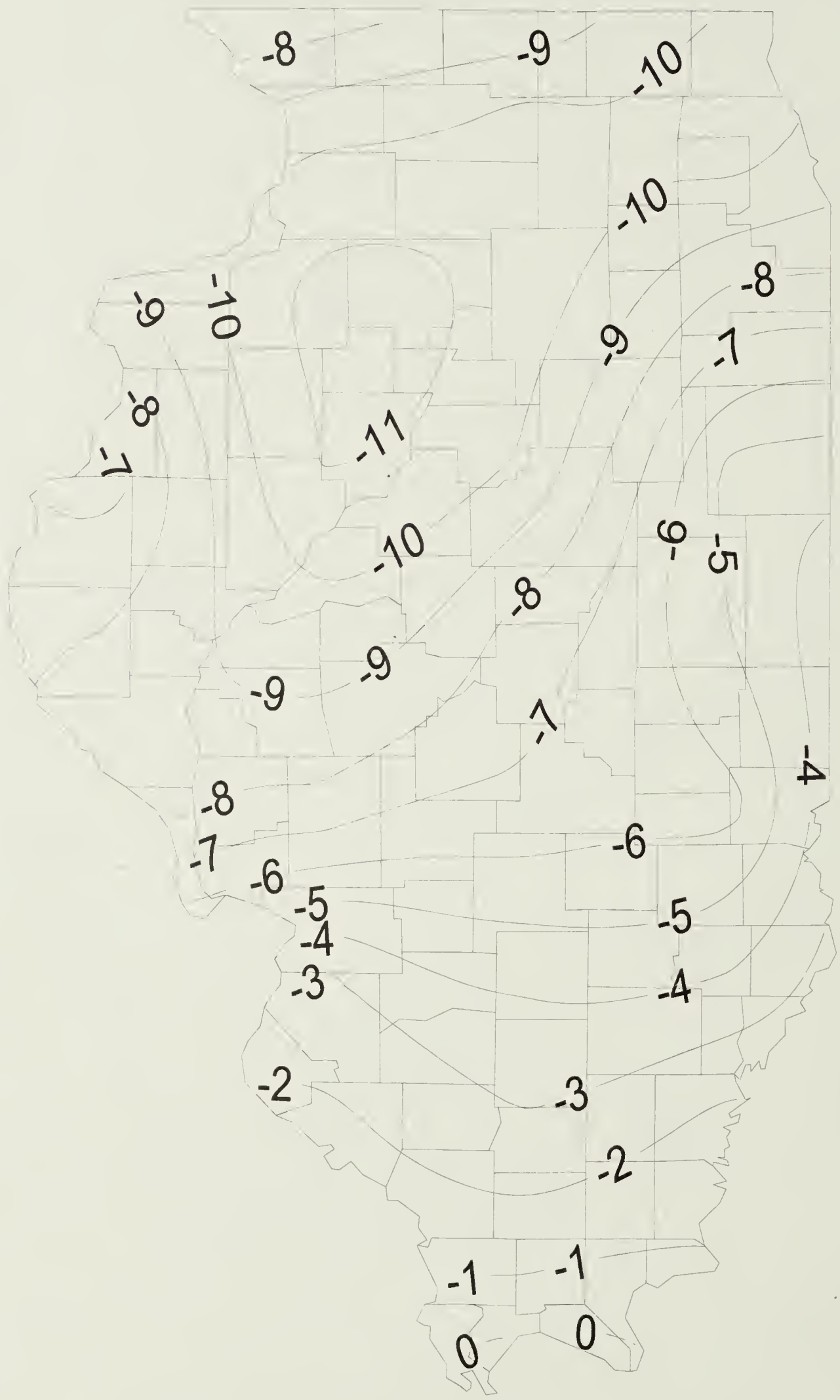


Figure 7. The accumulated contribution of total rainfall (inches) of the four tropical systems that passed through Illinois during the 2005 growing season.

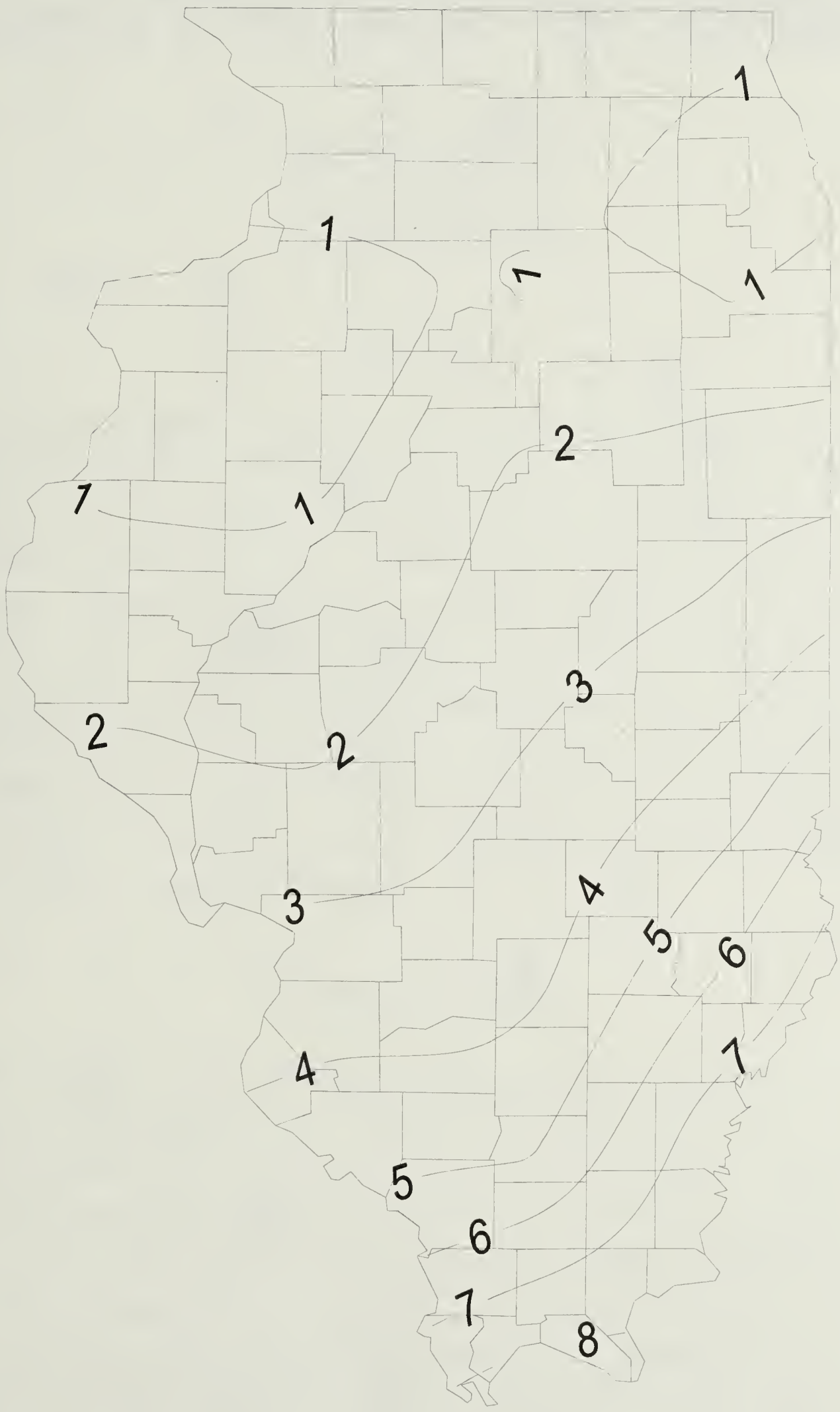
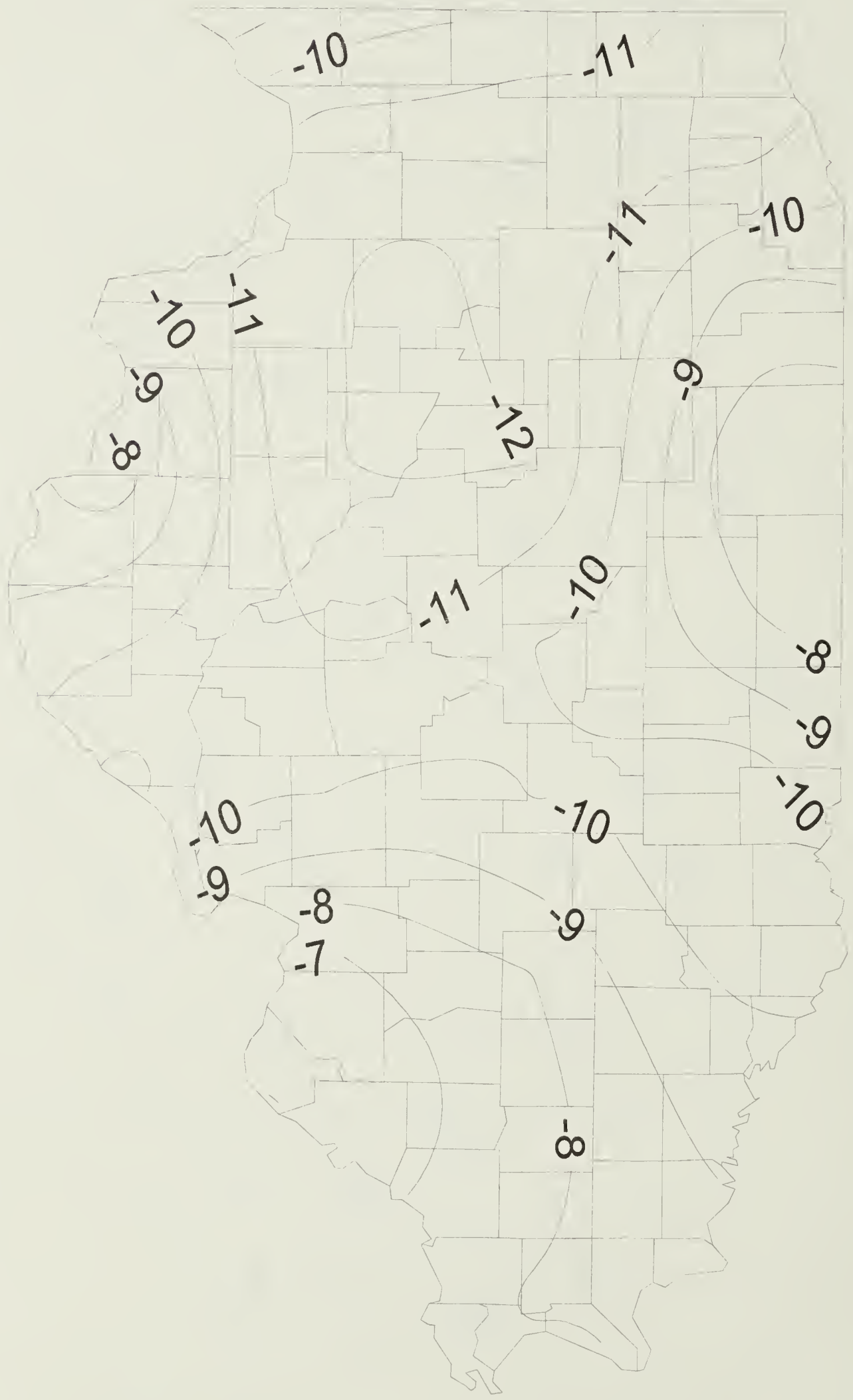


Figure 8. The March-September rainfall pattern, expressed as a departure from normal (1971-2000) in inches, with the rainfall of the four tropical systems that passed through Illinois during the 2005 growing season removed.



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The Influence of Prescribed Burning on Spiders and Pseudoscorpions: Known Predators of Woodland Litter Springtails

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ABSTRACT

To test the effect of prescribed burning on spiders and pseudoscorpions, leaf litter samples of invertebrates were collected from the East Woods of the Morton Arboretum. Of 162 samples extracted through modified Tullgren funnels, half were taken from previously burned areas and half from areas that had not been burned. Four years of data for each of three seasons within a span of 12 years were analyzed. Significantly fewer individual spiders were collected in burned areas than in unburned areas. Pseudoscorpions were present in approximately equal numbers in burned and unburned areas. Species diversity was greater for spiders than for pseudoscorpions with 12 families, 30 genera, and 22 species of spiders represented in the samples. Only 3 species of pseudoscorpions were collected. Results of this study suggest that to maintain or increase diversity of these invertebrates in natural environments where controlled burning is used as a management tool, frequency of burns should be changed from annual to every two or three years. In addition, several fire exclusion areas should be included that can serve as refuges for fire sensitive species to repopulate burned areas.

INTRODUCTION

Prescribed burning is used as a management practice to: 1) restore natural fire processes, 2) enhance growth of preferred native species of plants that evolved with fire as a natural component of the environment, and 3) eradicate or reduce non-native plant species. In one study of upland forests of the Chicago region, however, abundance of garlic mustard (a non-native plant)was enhanced in burned areas over unburned areas (Bowles et al, 2000). In addition to managing plant species, it is often desirable to investigate the animal components of the ecosystem to find out how such fires affect animal species (Greenslade, 1997; York, 1994). The physical structure of the litter of Heathland, a woody shrub habitat of the North York Moors in England, was studied to ascertain the effects of burning and cutting on the arthropod fauna (Usher and Smart, 1988). Results suggested in this study that fewer spiders in burnt areas might be due to more favorable open areas for bird predation than in the cut areas of heath. Species diversity information was limited as only one of 42 species of spiders was sufficiently abundant for statistical analysis. It has also been shown that the structural complexity of leaf litter significantly affected the abun-

dances of some forest floor spiders, especially web building species (Bultman and Uetz, 1982; Duffey, 1978). Because prescribed fire affects the depth of leaf litter remaining, the epigeic fauna of a forest floor ecosystem in Australia had significantly lower numbers of spiders than adjacent unburnt areas (York, 1999). Successional changes in spider species after prescribed burning and decreases in total spider density were also reported in Finland with signs of recovery occurring only after 7-13 years (Huhta, 1971). However, in chestnut forests of south-facing slopes of the Alps, the numbers of spider species increased in areas of recurring fires over similar forests that had not been burned or burned only once (Moretti, 2000). Some studies on wildfires have shown that it may take 15-30 years for populations of linyphiid spiders to recover from wildfires (Buddle, et al., 2000).

Prescribed burning of woodland litter reduced springtail (Order Collembola) species richness as well as yearly and seasonal density (Brand, 2002). Because burning has been shown to affect springtail species richness and density, burning may also affect springtail predator diversity and density. Spiders prey on springtails in the litter layer of woodlands (Hallander, 1970). When spiders were removed experimentally, populations of springtails increase over those in control areas (Reichert and Bishop, 1990; Clarke and Grant, 1968). The purpose of my study at The Morton Arboretum in Lisle, Illinois, was to evaluate the effect of prescribed burning on spiders, pseudoscorpions, and the leaf litter in which they live. The effect of fire may be direct removal of predators or indirect if it reduces predator food supply.

Pseudoscorpions are common inhabitants of woodland leaf litter (Jones, 1970) and are known predators of springtails (Weygoldt, 1969). There are higher numbers of pseudoscorpions in less disturbed field margins than in those subject to mowing (Bell et al., 1999).

METHODS/STUDY SITE

The East Woods of The Morton Arboretum was used for my study that extended over 12 years with collections in the 4 years 1987,1989,1997, and 1998. Of the 680 hectares at the Arboretum, about 110 hectares are covered by the East Woods and 20 hectares have been burned annually in the spring after snow melt since 1987. Prescribed burning has been used at the Arboretum as a management technique to restore fire processes of the past and encourage the growth of diverse, hardwood deciduous species. Two known predators of springtails, spiders and pseudoscorpions, were collected in litter samples and extracted using modified Tullgren funnel techniques. Although the screen mesh was designed specifically for small arthropods, the large openings at the junction of screen and funnel permitted all but the largest spiders to be collected. Specimens were collected in a bottle of Van Torne's preservative (Christiansen and Bellinger, 1980) at the base of each funnel. Spiders and pseudoscorpions were sorted using a Bausch & Lomb 7-30X microscope and stored in individual vials of 70% isopropyl alcohol for future identification. Litter was not weighed in 1987, but was weighed for the other three years. To study the effect of fire, an experimental design was established in which 126 random samples (0.2 m^2 area) of woodland leaf litter from 13 one acre plots distributed throughout the East Woods were collected in 3 different seasons (excluding winter) over four years. An equal number of samples (63) were collected from previously burned areas and from

areas that had not been previously burned. Litter was placed in plastic bags and transported to the extraction funnel location in insulated coolers. Details concerning vegetation of the site and collection methods were published earlier (Brand, 2002). Data were gathered on species richness, frequency and density of spiders and pseudoscorpions, and dry weight of leaf litter. The software program Statistix 7 (Analytical Software 2000) was used to perform ANOVA or nonparametric Kruskal-Wallis ANOVA tests on data for all samples from previously burned and unburned areas. The Kruskal-Wallis test was used if the variances were heterogeneous and the distributions non-normal.

RESULTS

Results of the overall study are provided first, followed by the effect of fire on spiders, pseudoscorpions, and leaf litter. Taxonomic placement of genera and species of spiders by family is provided in Table 1.

Spiders

Many of the 419 spiders collected were immature, thus taxonomic identification to family, genus, or species was restricted to 322 specimens (Table 1). Of the immature specimens, 55 were spiderlings for which only identification to family was possible. The remaining 42 were juveniles for which only genus could be identified. Of the twelve families represented in the study, two families, Agelenidae and Uloboridae, were not represented in collections from unburned areas and the family Dictynidae (web builders) was not sampled in burned areas. Specimens from 30 genera were collected in the study. Of these, 7 genera were not represented in unburned areas and 7 genera were not represented in burned areas. The number of specimens identified to species was insufficient to compare effects of burning at the species level. A few spiders were identified as new species but these have not yet been described.

The number of spiders per $0.2m^2$ sample ranged from 0 to 38 with a mean (x_m) of 2.59 and a standard error (S.E.) of 0.30. Density per square meter ranged from 0 to 204 with a x_m of 13.93 ± S.E. of 1.63. Mean density varied significantly over the 4 years with the highest mean density in 1998. Seasonal density for the 3 seasons (winters excluded) also varied significantly (Table 2).

Density of spiders per square meter in burned areas was significantly lower than in unburned areas (Table 3). However, for any given year there was no difference in spider density from burned versus unburned areas. There were significantly more spiders in unburned areas in spring than in burned areas, but no difference in density due to fire for summer and autumn seasons (Table 3).

Pseudoscorpions

Three species of pseudoscorpions (*Microbisium parvulum*, *Chthonius (Ephippiochthonius) tetrachelatus*, and *Hesperochernes canadensis*) were identified in the 193 specimens collected (Table 4B). Individuals of *M. parvulum* were most numerous (186), followed by *C. tetrachelatus* (6), and *H. canadensis* (1). It is the first time this latter species has been reported from Illinois (M. Harvey, pers. comm.). The number of pseudoscorpions per $0.2m^2$ ranged from 0 to 9 with xm of 1.2 ± 0.14. Density per square meter ranged from 0 to 45 with x_m of 6.0 ± 0.70. Mean density varied significantly over the 4 years

with highest mean density occurring in 1998, the same year in which the spiders had the highest density (Table 4A). Seasonal variation in density was not significant (Table 4A). No significant effect of prescribed burning on pseudoscorpion density was demonstrated (Table 5). However, there were more pseudoscorpions from unburned areas (108) than burned areas (85), and 4 of 6 specimens of *C. tetrachelatus* and the single specimen of *H. canadensis* were from unburned areas. Density was significantly different only in 1987 with lower density in burned areas. No differences in density were demonstrated for any of the seasons as a result of prescribed burning (Table 5).

Litter

In 1989,1997, and 1998 litter was collected, dried, and weighed. For 126 samples, the mean and standard error was 2.13 kg/m. and ± 0.09. There was no significant difference in annual variation in mean litter weight over three years, but seasonal variation was highly significant with spring having the highest litter weight (Table 6). A significant effect of burning was demonstrated with more litter present in the unburned areas than burned areas. The same effect was seen in each year of the study but there were no differences of the effect of burning on mean litter weight within any of the 3 seasons (Table 7).

DISCUSSION

Information about invertebrate components can provide an essential link to improve management of woodland ecosystems (Naeem, S. et al, 1995, Hunter, M.D. et al, 2003, Reynolds, B.C. et al, 2003). Recent studies of decomposition rate in a forest ecosystem showed that spiders influence the chemistry of decomposition (Hunter M.D. et al, 2003). Although the present study could not be replicated in detail at other sites, a preliminary investigation of the effect of burning on similar predators was conducted in 1997 and 1998 at the oak-hickory wooded knolls of Lincoln Marsh, Wheaton, Illinois. Of the 54 samples collected over 3 seasons, 27 each from previously burned and unburned areas, the numbers of these predators (spiders and pseudoscorpions) were insufficient to demonstrate significant differences of the effect of fire (unpublished data). Over the four years of the present study there was a significant difference in the density of spiders with increasing density over time (Table 2). Similarly, pseudoscorpions also had a significant increase in density with the exception of the third year, 1997 (Table 4). In a previous study of springtails in this area (Brand, 2002), the same pattern of significantly increased density occurred. In 1998, the final year of the study, all three invertebrate species (springtails, spiders, and pseudoscorpions) showed their highest densities. This year also had the highest precipitation (Morton Arboretum weather station records) for periods prior to sampling (Brand, 2002). However, litter weight did not follow this pattern and was not significantly different in the three years that litter weight was measured. There was a significant difference in litter weight by season with more litter in the spring prior to increased decomposition at higher temperatures in the summer and autumn (Table 6). The effect of fire on litter was evident in each year of the study with significant variation in dry weight for each year (Table 7). Reduced density of spiders in the spring from burning was statistically significant but this seasonal effect of burning was not significant for pseudoscorpions or litter (Tables 3, 5, and 7).

When prescribed burning is a part of the management protocol, understanding the effects of fire on density and diversity of invertebrate populations can contribute to more suc-

cessful ecological restorations. In my study spiders and pseudoscorpions responded differently to fire. Spiders were significantly less dense in areas that were burned whereas pseudoscorpions showed no difference in density between burned and unburned areas. This may reflect a behavioral difference in which larger, mobile spiders are more active on the surface of litter and subject to higher mortality from fire than smaller pseudoscorpions closer to the ground surface. Despite availability of some safe havens under logs, stones, and exposed tree roots during prescribed burning, diversity of invertebrate and plant species would be enhanced if prescribed burns occurred every two or three years rather than annually. A reduced frequency of burning may more adequately reflect the historical occurrence of naturally occurring fires than the regular annual burns often used in current management practice.

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Beth Johnson, Mary Beth Stevenson, and Steve Anderson provided technical assistance. Pseudoscorpion identification was done by Mark Harvey and spider identification by Thomas R. Prentice. Specimens collected have been deposited in the Field Museum, Chicago, Illinois. The Illinois Department of Natural Resources granted partial funding and The Morton Arboretum provided additional resources.

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Table 1. List of spiders.

Family	Genus and species	Family	Genus and species
Agelenidae	*Agelenopsis* sp.	Linyphiidae	*Meioneta evadens*
Anyphaenidae	*Anyphaena* sp.		*M. unimaculata*
	Hibana		*Microneta viaria*
	Oxysoma		*Walckenaeria sprialis*
Clubionidae	*Clubiona* sp.	Lycosidae	*Schizocosa (oscota)**
	Clubionoides		*S.* sp.*
Corinnidae	*Phruokripus alarius*		*Picuta*
	Scotinella madisonia	Salticidae	*Bianor*
	Castianeira sp.		*Neon*
Dictynidae	*Tricholathys* sp.	Theridiidae	*Endoplognatha ovata*
Hahniidae	*Neoartistea* sp.		*E. (tecta)**
Linyphiidae	*Bathyphantes alboventris*		*E.* sp.**
	Centromeris cornupalpis		*Theridion* sp.
	Corammorota sp.	Thomisidae	*Misunenops* sp.
	Eperigone autumnalis		*Ozyphila monroensis*
	E. maculata		*O.* sp.**
	E. sp. undescribed		*Xysticus fraternis*
	Gnathonaroides pedolis		*X.* sp.**
	Kaestneria sp.	Uloboridae	*Uloborus* sp.

( )* - most likely this species
** - different but unknown species than listed for genus

Table 2. Density of spiders for all samples plus annual and seasonal variation. (X_m/m^2)

Annual Variation
KW = 67.1 $p < 0.001$**

Year	N	X_m	S.E.
1987	36	1.89	0.64
1989	36	7.42	1.59
1997	54	19.35	4.03
1998	36	24.33	2.37
All Samples	162	13.93	1.63

Seasonal Variation
KW = 7.81 $p < 0.03$*

Season	N	X_m	S.E.
Spring	54	15.74	0.31
Summer	36	15.92	1.13
Autumn	72	11.57	0.31

N = number of samples; X_m = mean of individuals, S.E. = standard error

Table 3. Effect of fire on spiders (X_m/m^2).

	Burned			Unburned				
	N	X_m	S.E.	N	X_m	S.E.	Analysis	p Value
All samples	81	12.61	2.89	81	15.21	1.53	KW =7.44	p < 0.01**
Annual Variation								
1987	18	2.06	0.89	18	1.72	0.95	F = 0.07	p = 0.80
1989	27	5.56	1.34	9	13	4.62	KW = 3.3	p = 0.07
1997	27	21.31	7.78	27	17.4	2.35	KW = 1.84	p = 0.18
1998	9	28.89	5.85	27	22.82	2.5	F = 1.24	p = 0.27
Seasonal Variation								
Spring	18	7.78	1.72	36	19.72	2.03	KW =12.3	p < .001**
Summer	27	16.9	7.99	9	13	4.62	KW = 1.28	p = 0.26
Autumn	36	11.83	2.44	36	11.31	2.37	F = 0.02	p = 0.88

N = number of samples; X_m = mean of individuals, S.E. = standard error

Table 4. Annual/season variation density (X_m/m^2) and identification of pseudoscorpions.

A) Annual and seasonal variation density

	N	X_m	S.E.		N	X_m	S.E.
Annual Variation				Seasonal Variation			
F = 3.34 p < 0.03*				F = 0.41 p = 0.66			
1987	36	5.17	1.36				
1989	36	6.11	1.71	Spring	54	6.91	1.51
1997	54	4.43	1.201	Summer	36	5.06	1.64
1998	36	10.8	1.96	Autumn	72	6.63	1.07
All samples	162	6.37	0.781				

N = number of samples; X_m = mean of individuals, S.E. = standard error

B) Identification of pseudoscorpions

Family	Genus and species
Chemetidae	*Microbisium parvulum*
Chthoniidae	*Chthonius tetrachelatus*
Neobisiidae	*Hesperochemes canadensis*

Table 5. Effect of fire on pseudoscorpions (X_m/m^2).

	Burned			Unburned				
	N	X_m	S.E.	N	X_m	S.E.	Analysis	p Value
All samples	81	5.6	1.09	81	7.11	1.12	F = 0.99	p = 0.32
Annual Variation								
1987	18	3.78	1.28	18	6.56	2.36	KW = 19.4	p < .001**
1989	27	6.15	2.07	9	6.01	3.06	KW = 0.01	p = 0.18
1997	27	5.7	2.21	27	3.15	0.92	KW = 0.07	p = 0.80
1998	9	7.22	3.01	27	11.93	2.41	F = 1.08	p = 0.31
Seasonal Variation								
Spring	18	7.72	2.82	36	6.5	1.8	F = 0.14	p = 0.71
Summer	27	4.74	1.96	9	6	3.06	F = 0.11	p = 0.74
Autumn	36	5.17	1.39	36	8.08	1.62	F = 1.87	p = 0.18

N = number of samples; X_m = mean of individuals, S.E. = standard error

Table 6. Dry weight of litter for all samples plus annual and seasonal variation (kg/m^2).

	N	X_m	S.E.		N	X_m	S.E.
Annual Variation				Seasonal Variation			
KW = 2.21 p < 0.33				KW = 57.0 p < 0.01**			
1989	36	2	0.2	Spring	54	2.8	0.1
1997	54	2.3	0.2	Summer	36	1.3	0.1
1998	36	1.9	0.1	Autumn	72	1.9	0.1
All samples	126	2.1	0.1				

N = number of samples; X_m = mean of individuals, S.E. = standard error

Table 7. Effect of fire on litter (X_m/m^2).

	Burned			Unburned				
	N	X_m	S.E.	N	X_m	S.E.	Analysis	p Value
All samples	72	1.92	0.11	54	2.39	0.15	KW = 7.22	p < 0.01*
Annual Variation								
1989	18	1.51	0.23	9	2.22	0.21	KW = 4.81	p < 0.03*
1997	27	1.81	0.21	27	2.85	0.21	F = 12.83	p < 0.001*
1998	27	1.53	0.11	27	2.12	0.15	KW = 5.88	p < 0.02*
Seasonal Variation								
Spring	18	2.8	0.19	36	2.79	0.18	F = 0.0	p = 0.98
Summer	27	1.35	0.16	9	1.32	0.12	KW = 0.49	p = 0.49
Autumn	18	1.98	0.2	36	1.79	0.13	F = 0.61	p = 0.44

N = number of samples; X_m = mean of individuals, S.E. = standard error

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Avian Spring Arrival Differences in East-central Illinois, 1903-1922 and 1965-1987

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ABSTRACT

Median spring arrival dates for 74 avian species migrating through east-central Illinois were recorded around Urbana, Champaign County, 1903-1922, and near Charleston, Coles County, 1965-1987. Only 11% had an expected lag of 2-3 days later in their median arrivals in Urbana than 74 km farther south in Charleston; arrivals of individual species varied by 12 days earlier to 30 days later in Urbana than decades later in Charleston. Changes in climate or in population size over time may have contributed to marked differences for some of these species as well as for several others where yearly observations were rare at one site or the other. For a few nesting species availability of key bottomland forest habitat in Coles County but not in Champaign County could explain their infrequent records or late arrivals in Urbana.

INTRODUCTION

Phenology, the study of recurring seasonal events in the life cycles of plants and animals, enables one to compare the timing of such events in different geographic locations or over different time intervals. In Wisconsin between 1935 and 1945, Aldo Leopold compiled a phenological calendar of yearly biological activities recorded around Madison and farther northwest on the family farm near Baraboo. Among 325 annual events were spring arrival dates for 39 species of migrant birds (Leopold and Jones 1947). Years later, Nina Leopold Bradley published an analytical comparison of her father's 1936-1947 spring records on their farm with her own 1976-1998 observations at that same site. Included were 74 series of recurring events including arrival dates for 18 bird species (Bradley et al. 1999).

My objective was to compare spring arrival dates in 1965-1987, for birds recorded near Charleston in Coles County with those reported during 1903-1922 by Smith (1930) near Urbana in Champaign County, 74 km north of Charleston. Included are plausible explanations for species having marked arrival differences.

METHODS

Frank Smith, with help from "competent and interested observers," kept daily field notes of birds seen near the University of Illinois, Urbana campus during spring seasons of 1903 to 1922. He published data on 221 species including median arrival dates for those seen regularly during the 20-year span (Smith 1930).

I also recorded almost daily notes on migratory activity near Charleston in Coles County plus notes from other capable observers during 1965-1987 with arrival records of select species extending until 2005. As did Smith, I calculated median dates of first arrivals to minimize the skewing effects of occasional extreme records or clusters of dates that affect means and modes. In my tabular comparisons of species at the two sites I only listed regular migrants recorded in at least 70% of the total years sampled (14 of 20 in Urbana and 16 of 23 in Charleston). Omitted are those that occasionally overwinter making first arrivals uncertain. Waterbirds, marsh and shorebirds were excluded because Smith regarded these as less adequately studied, causing doubt about their actual arrivals. Without annual arrival dates in Smith's paper, I elected not to include correlation or regression analyses for my own data. I did include statistics from an earlier paper on the variability in yearly spring arrivals of certain species in Coles County. Scientific names appear in the Appendix to reduce clutter in text and tables that follow.

RESULTS

The median arrival dates of the 74 migrant pairs in this report include 17 recorded in Urbana during February-March (Table 1), 25 in April (Table 2) and 32 in May (Table 3). The species lists are in taxonomic order rather than by chronological dates to facilitate easy comparison of related groups. The earliest arriving species are all short-distance migrants wintering mostly in the United States that periodically are confronted by harsh survival conditions as winter weather lingers or recurs (Table 1). The mean difference for this initial group was 0.8 days earlier in Urbana. There were, however, considerable arrival differences for some species between sites over the half century. Of the 17 species, 10 were recorded earliest near Urbana including most sparrows but decades later blackbird members were conspicuously early around Charleston.

Among the 25 migrant species that usually arrived in Urbana in April (Table 2), all winter mainly outside the U.S. but seven (Turkey Vulture, House Wren, Blue-gray Gnatcatcher, Gray Catbird, Yellow-rumped Warbler, Palm Warbler, and Common Yellowthroat). During April the group mean difference was 3.4 days earlier in Charleston; omitting Turkey Vulture dates, the mean was 2.2 days earlier for the other 24 species. Sixteen species occurred earlier in Charleston but three of the four thrushes appeared first in Urbana (as did the Hermit Thrush in March).

During May, the peak landbird migration period in Illinois (Table 3), all 32 species except the Lincoln's Sparrow are long-distance migrants wintering mostly in the tropics. The mean arrival date was 3.2 days earlier in Charleston for this group. The four vireos averaged more than a week earlier in Charleston and the Northern Parula, a warbler, nearly 3 weeks earlier. Only nine species averaged earlier median arrival dates at Urbana early in the century and usually by only 1-2 days.

Several species that lacked adequate yearly records for inclusion in the tables are of particular interest. Early in the past century seven species were found nearly every spring near Urbana but more than 40 years later they were recorded at Charleston in less than half the 23 years: Olive-sided Flycatcher, Yellow-bellied Flycatcher (5 years), Bewick's Wren (8 years and none after 1984), Winter Wren, Loggerhead Shrike, Black-throated Blue Warbler (3 years) and Pine Warbler. By contrast, the White-eyed Vireo, Cerulean Warbler and Yellow-throated Warbler were found in at least 20 of 23 springs around Charleston, the Worm-eating Warbler has occurred locally in 33 of the past 40 years and the Louisiana Waterthrush yearly since 1975 through 2005 in my records. From 1903-1922 at Urbana, none of these latter five species were seen in more than 6 of 20 years with the Cerulean Warbler found only once and the Yellow-throated Warbler not listed.

DISCUSSION

Median arrival date differences between Urbana, 1903-1922 and Charleston, 1965-1987 might have resulted from the latitudinal distance separating the two sites, changes in climate, changes in population size, or habitat differences limiting the presence of some species. Each of these possibilities will be considered with supporting evidence from other studies.

In the northern hemisphere most phenological events follow the warming sun and longer days northward in spring; thus migrants would be expected to arrive somewhat later in Urbana, 74 km north of Charleston. To compare the timing of such events at distant locations, Hopkins (1918) proposed his Bioclimatic Law, a rule-of-thumb formula to measure the average spring delay in days as one travels northward, eastward and upward in elevation. If his latitudinal component is valid, in a typical year migrating birds should arrive in Urbana 2.7 days after reaching Charleston.

Using Hopkins' rule, Leopold and Jones (1947) calculated dates for biological activities at their two Wisconsin sites to be 1.5 days later at the more northerly farm. They actually observed average flowering dates to be 2.6 days later in April and 3.6 days later in May. Their bird arrival data were excluded because of weekday gaps in farm records near Baraboo.

When median migrant arrival dates near Baraboo were compared with Charleston for similar years (Hunt and Cope 1996), Hopkins' rule predicted a delay of 16.1 days. In fact, February-March arrivals in Baraboo averaged 25.5 days later than Charleston, April migrants were 8.3 days later and May birds were 6.2 days later. Thus, the rule is a poor predictor for highly mobile birds that can traverse 68-80 km in 2-3 hours and as shown above, speed up their transit as the season progresses. At best the rule might account for 8 of 74 species with 2 to 3-day average delays between Charleston and Urbana but most species fell outside this range.

In Wisconsin, Temple and Cary (1987) reported considerable differences in year-to-year migration peaks among the earliest arrivals; nearly all were short-distance migrants responding to regional temperatures. Later arriving, long-distance travelers wintering in

the tropics that depend more on photoperiod for timing displayed less variation between years.

Among 91 spring migrants reported by Hunt and Cope (1996), the ten species with the least annual variability in their arrivals in eastern Illinois and eastern Indiana had median dates between April 14 and May 7. All but two were long-distance migrants. From my Coles County 1965-1987 records in their table 4, each species is listed below by increasing variability with its sample years – mean arrival dates – standard errors – range of arrival days: Chimney Swift – 22 – 4/15 – 0.57 – 10; Rose-breasted Grosbeak – 22 – 4/28 – 0.67 – 13; Magnolia Warbler – 22 – 5/07 – 0.73 – 15; Least Flycatcher – 20 – 5/02 – 0.75 – 12; Cape May Warbler – 19 – 5/05 – 0.78 – 12; Eastern Wood-Pewee – 21 – 5/04 – 0.79 – 17; Baltimore Oriole – 22 – 4/26 – 0.81 – 14; Common Yellowthroat – 22 – 4/23 – 0.83 – 14; Great Crested Flycatcher – 22 – 4/29 – 0.89 – 17; Gray Catbird – 22 – 4/26 – 0.95 – 17. At the other extreme, my unpublished species with the greatest yearly variability near Charleston was the Turkey Vulture, an early, short-distance migrant: 21 – 3/01 – 2.82 – 44. Without yearly records in the Smith (1930) report, I can only assume the variability of spring arrivals in Urbana for these same species was comparable.

Because a delay of 2.7 days predicted by Hopkins (1918) for the latitudinal difference between Charleston and Urbana failed to explain arrival differences for most species, the two sites could be treated as one and comparisons made of two recording intervals separated by several decades similar to the following study. To test the hypothesis that global warming has been altering biological responses, Nina Leopold Bradley compared her annual observations on the Leopold farm during 1976-1998 with those of her father in 1936-1947 (Bradley et al. 1999). With the emphasis on phenological changes over six decades, they plotted statistically significant regressions of lake ice melt through the years with a rise in March temperatures, earlier spring flowering dates and migrant arrivals. Of 18 bird species they compared, eight were significantly earlier, six were marginally earlier and four did not respond to temperature change.

Of the five species in the current study that Bradley et al. (1999) classified as significant responders to spring temperature increases in Wisconsin, median arrivals of Whip-poor-will, House Wren, Rose-breasted Grosbeak, and Red-winged Blackbird in east-central Illinois averaged 7.5 days earlier in the more recent time span; Brown-headed Cowbird arrivals were identical for both study periods. Among other migrants, all four vireos averaged 7.8 days earlier in the 1965-1987 period and 12 of 22 warblers averaged 1.8 days earlier but median arrivals by four of five thrushes were 3.8 days later. These differences indicate not all travel schedules are determined by identical sets of stimuli.

Unfortunately, long-term average winter-spring temperatures for east-central Illinois are difficult to obtain although Chagnon (1990) reported a yearly warming trend statewide 1890-1940 followed by a cooling trend through 1985. The lack of yearly arrival dates by Smith (1930) also precluded the use of regressional analyses for the sequence of Illinois data sets, the basis for the Bradley et al. (1999) conclusions.

Also to be considered is the influence of population size on variation in arrival times and the frequency of years during which individuals are likely to be seen. Both Smith (1930) and Leopold and Jones (1947) made the point that large populations are more readily

detected than smaller numbers, resulting in earlier and more frequently recorded arrivals. Consider the Turkey Vulture median arrivals (Table 2) – 30 days earlier in 1965-1987 (Charleston) than in 1903-1922 (Urbana) and on average 41 days earlier in 1988-2005 than previously in Urbana. This dramatic change might suggest a long sequence of milder weather shifting their winter range northward but it could also result from a growing population where some migrants leave the winter roosts earlier. Bohlen (1989) cited a report that Turkey Vulture populations had increased between 1909 and 1958 in central Illinois, a trend that may have continued. For Barn Swallows to average 15 days sooner than early in the century (Table 2) may have a similar explanation. Graber et al. (1972) describe "striking population changes through the years in Illinois," citing a three-fold increase of the central Illinois nesting population from 1907-1909 to 1957-1958.

Long-term Midwest declines of other species probably account for infrequent sightings during 1965-1987. Bewick's Wrens were seen in all 20 years of Smith's study but were found in only 8 of 23 years in Charleston with the last in 1986. Bohlen (1989) stated the decline has been so drastic the species rarely nests in Illinois and is on the state endangered species list. Early in the past century Smith also found Loggerhead Shrikes yearly near Urbana but recently around Charleston there are only 19 spring shrike records in the 40 years since 1965. According to Graber et al. (1973), "most of the population in northern and central Illinois has disappeared since 1965."

Black-throated Blue Warblers also occurred annually in Urbana but are rarely seen near Charleston – only three springs during 1965-1987 and only three more times through 2005. Graber et al. (1983) said this species had "probably experienced a serious population decline in the past century." They also believe there has been a lesser decline of Pine Warblers migrating through central Illinois. This latter species has been observed in only 6 of 23 spring migrations in Charleston. Separate monographs by these same authors on flycatchers and vireos make no mention of population changes that might explain why Olive-sided and Yellow-bellied Flycatchers were once common in Urbana but recently scarce near Charleston nor why White-eyed Vireo records are numerous here but infrequent during Smith's (1930) Urbana study.

Still other species with differing spring migration histories were probably affected more by the geologic history and landforms of the two study areas than by the distance or decades separating them. The Wisconsin glacial advance scoured Champaign County around Urbana creating a rather flat, prairie landscape that lacked extensive forests and waterways. That same glacier stopped abruptly in Coles County leaving a terminal moraine that was penetrated by the Embarras River with its watershed of steep ravines and mature bottomland hardwoods (V.P. Gutowski, pers. com.). Much of this riverine forest still exists because of timber harvesting difficulties and it is here the Cerulean, Yellow-throated, and Worm-eating Warblers, Louisiana Waterthrushes and Northern Parulas arrive early in spring and linger into summer. In Urbana transient Northern Parulas didn't arrive until 20 days later and the other four were rarely or never reported by Smith. Recently, for the Illinois Breeding Bird Atlas (Kleen et al. 2004), several of these species were found nesting in Coles County but were scarcely represented in Champaign County surveys.

One should not be surprised by avian spring migration calendars that vary from area to area or from time to time but only with more detailed information can one hope to explain differences exhibited by individual species.

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Table 1. February-March median arrival dates in Urbana, 1903-1922, and Charleston, 1965-1987, with years (n) and days difference.

Species	1903-22 (20)	1965-87 (23)	Difference
Killdeer	3-01 (20)	2-21 (21)	-8
Yellow-bellied Sapsucker	3-26 (20)	3-29 (21)	+3
Eastern Phoebe	3-17 (18)	3-22 (22)	+5
Ruby-crowned Kinglet	3-28 (20)	4-07 (22)	+10
Eastern Bluebird	2-23 (17)	2-24 (22)	+1
Hermit Thrush	3-31 (18)	4-08 (21)	+8
Brown Thrasher	3-27 (19)	3-25 (22)	-2
Eastern Towhee	3-11 (20)	3-14 (22)	+3
Chipping Sparrow	3-23 (20)	4-04 (20)	+12
Field Sparrow	3-22 (20)	3-17 (22)	-5
Vesper Sparrow	3-28 (19)	4-03 (20)	+6
Fox Sparrow	3-01 (20)	3-11 (21)	+10
Swamp Sparrow	3-19 (20)	3-22 (20)	+3
Red-winged Blackbird	3-06 (19)	2-20 (22)	-14
Eastern Meadowlark	2-26 (20)	2-13 (17)	-13
Rusty Blackbird	3-08 (19)	3-02 (16)	-6
Brown-headed Cowbird	3-11 (19)	3-11 (21)	0

Table 2. April median arrival dates in Urbana, 1903-1922, and Charleston, 1965-1987, with years (n) and days difference.

Species	1903-22 (20)	1965-87 (23)	Difference
Turkey Vulture	4-01 (16)	3-02 (21)	-30
Broad-winged Hawk	4-28 (16)	4-17 (17)	-11
Whip-poor-will	4-24 (19)	4-17 (21)	-7
Chimney Swift	4-20 (18)	4-14 (22)	-6
Least Flycatcher	4-30 (16)	5-02 (20)	+2
Eastern Kingbird	4-27 (20)	4-26 (22)	-1
Purple Martin	4-09 (18)	3-31 (22)	-9
Bank Swallow	4-20 (16)	4-26 (18)	+6
Barn Swallow	4-25 (16)	4-10 (20)	-15
House Wren	4-21 (20)	4-15 (22)	-6
Blue-gray Gnatcatcher	4-14 (20)	4-12 (22)	-2
Veery	4-29 (18)	5-05 (19)	+6
Gray-cheeked Thrush	4-29 (19)	5-03 (22)	+4
Swainson's Thrush	4-25 (20)	5-01 (22)	+6
Wood Thrush	4-30 (20)	4-25 (21)	-5
Gray Catbird	4-26 (16)	4-26 (22)	0
Yellow-rumped Warbler	4-09 (20)	4-06 (22)	-3
Black-throated Green Warbler	4-27 (20)	4-29 (22)	+2
Palm Warbler	4-22 (20)	4-22 (22)	0
Black-and-white Warbler	4-24 (20)	4-29 (22)	+5
Northern Waterthrush	4-30 (20)	4-23 (21)	-7
Common Yellowthroat	4-29 (20)	4-24 (22)	-5
Scarlet Tanager	4-30 (20)	4-27 (22)	-3
Rose-breasted Grosbeak	4-30 (20)	4-27 (22)	-3
Baltimore Oriole	4-29 (18)	4-26 (22)	-3

Table 3. May median arrival dates in Urbana, 1903-1922, and Charleston, 1965-1987, with years (n) and days difference.

Species	1903-22 (20)	1965-87 (23)	Difference
Black-billed Cuckoo	5-13 (20)	5-06 (19)	-7
Yellow-billed Cuckoo	5-05 (18)	5-07 (21)	+2
Common Nighthawk	5-07 (20)	4-28 (20)	-9
Ruby-throated Hummingbird	5-09 (20)	5-03 (21)	-6
Eastern Wood-Pewee	5-02 (14)	5-04 (21)	+2
Acadian Flycatcher	5-12 (19)	5-08 (20)	-4
Great Crested Flycatcher	5-01 (20)	4-29 (22)	-2
Yellow-throated Vireo	5-04 (19)	4-26 (20)	-8
Warbling Vireo	5-04 (16)	4-25 (22)	-9
Philadelphia Vireo	5-12 (19)	5-07 (17)	-5
Red-eyed Vireo	5-06 (20)	4-27 (19)	-9
Golden-winged Warbler	5-06 (16)	5-05 (21)	-1
Nashville Warbler	5-01 (20)	4-27 (22)	-4
Northern Parula	5-09 (15)	4-19 (21)	-20
Yellow Warbler	5-02 (20)	4-26 (21)	-6
Chestnut-sided Warbler	5-04 (20)	5-06 (22)	+2
Magnolia Warbler	5-02 (20)	5-07 (22)	+5
Cape May Warbler	5-05 (19)	5-05 (19)	0
Blackburnian Warbler	5-03 (20)	5-04 (22)	+1
Bay-breasted Warbler	5-08 (20)	5-09 (22)	+1
Blackpoll Warbler	5-09 (20)	5-04 (21)	-5
American Redstart	5-02 (20)	5-03 (22)	+1
Prothonotary Warbler	5-02 (14)	4-25 (19)	-7
Ovenbird	5-02 (20)	4-28 (21)	-4
Wilson's Warbler	5-11 (19)	5-10 (19)	-1
Canada Warbler	5-07 (14)	5-14 (21)	+7
Yellow-breasted Chat	5-04 (17)	5-03 (22)	-1
Lincoln's Sparrow	5-03 (19)	5-01 (20)	-2
Indigo Bunting	5-03 (20)	4-27 (22)	-6
Dickcissel	5-03 (20)	5-05 (21)	+2
Bobolink	5-04 (16)	5-03 (20)	-1
Orchard Oriole	5-04 (19)	4-26 (22)	-8

APPENDIX

Scientific names standardized by the American Ornithologists' Union (1998).

Turkey Vulture – *Cathartes aura*
Broad-winged Hawk – *Buteo platypterus*
Killdeer – *Charadrius vociferus*
Black-billed Cuckoo – *Coccyzus erythropthalmus*
Yellow-billed Cuckoo – *Coccyzus americanus*
Common Nighthawk – *Chordeiles minor*
Whip-poor-will – *Caprimulgus vociferus*
Chimney Swift – *Chaetura pelagica*
Ruby-throated Hummingbird – *Archilochus colubris*
Yellow-bellied Sapsucker – *Sphyrapicus varius*
Olive-sided Flycatcher – *Contopus cooperi*
Eastern Wood-Pewee – *Contopus virens*
Yellow-bellied Flycatcher – *Empidonax flaviventris*
Acadian Flycatcher – *Empidonax virescens*
Least Flycatcher – *Empidonax minimus*
Eastern Phoebe – *Sayornis phoebe*
Great Crested Flycatcher – *Myiarchus crinitus*
Eastern Kingbird – *Tyrannus tyrannus*
Loggerhead Shrike – *Lanius ludovicianus*
White-eyed Vireo – *Vireo griseus*
Yellow-throated Vireo – *Vireo flavifrons*
Warbling Vireo – *Vireo gilvus*
Philadelphia Vireo – *Vireo philadelphicus*
Red-eyed Vireo – *Vireo olivaceus*
Purple Martin – *Progne subis*
Bank Swallow – *Riparia riparia*
Barn Swallow – *Hirundo rustica*
Bewick's Wren – *Thryomanes bewickii*
House Wren – *Troglodytes aedon*
Winter Wren – *Troglodytes troglodytes*
Ruby-crowned Kinglet – *Regulus calendula*
Blue-gray Gnatcatcher – *Polioptila caerulea*
Eastern Bluebird – *Sialia sialis*
Veery – *Catharus fuscescens*
Gray-cheeked Thrush – *Catharus minimus*
Swainson's Thrush – *Catharus ustulatus*
Hermit Thrush – *Catharus guttatus*
Wood Thrush – *Hylocichla mustelina*
Gray Catbird – *Dumetella carolinensis*
Brown Thrasher – *Toxostoma rufum*
Golden-winged Warbler – *Vermivora chrysoptera*
Nashville Warbler – *Vermivora ruficapilla*
Northern Parula – *Parula Americana*
Yellow Warbler – *Dendroica petechia*
Chestnut-sided Warbler – *Dendroica pensylvanica*
Magnolia Warbler – *Dendroica magnolia*
Cape May Warbler – *Dendroica tigrina*
Black-throated Blue Warbler – *Dendroica caerulescens*
Yellow-rumped Warbler – *Dendroica coronata*
Black-throated Green Warbler – *Dendroica virens*
Blackburnian Warbler – *Dendroica fusca*
Yellow-throated Warbler – *Dendroica dominica*
Pine Warbler – *Dendroica pinus*
Palm Warbler – *Dendroica palmarum*
Bay-breasted Warbler – *Dendroica castanea*
Blackpoll Warbler – *Dendroica striata*
Cerulean Warbler – *Dendroica cerulea*
Black-and-white Warbler – *Mniotilta varia*
American Redstart – *Setophaga ruticilla*
Prothonotary Warbler – *Protonotaria citrea*
Worm-eating Warbler – *Helmitheros vermivora*
Ovenbird – *Seiurus aurocapillus*
Northern Waterthrush – *Seiurus noveboracensis*
Louisiana Waterthrush - *Seiurus motacilla*
Common Yellowthroat – *Geothlypis trichas*
Wilson's Warbler – *Wilsonia pusilla*
Canada Warbler – *Wilsonia canadensis*
Yellow-breasted Chat – *Icteria Virens*
Scarlet Tanager – *Piranga olivacea*
Eastern Towhee – *Pipilo erythrophthalmus*
Chipping Sparrow – *Spizella passerina*
Field Sparrow – *Spizella pusilla*
Vesper Sparrow – *Pooecetes gramineus*
Fox Sparrow – *Passerella iliaca*
Lincoln's Sparrow – *Melospiza lincolnii*
Swamp Sparrow – *Melospiza georgiana*
Rose-breasted Grosbeak – *Pheucticus ludovicianus*
Indigo Bunting – *Passerina cyanea*
Dickcissel – *Spiza americana*
Bobolink – *Dolichonyx oryzivorus*
Red-winged Blackbird – *Agelaius phoeniceus*
Eastern Meadowlark – *Sturnella magna*
Rusty Blackbird – *Euphagus carolinus*
Brown-headed Cowbird – *Molothrus ater*
Orchard Oriole – *Icterus spurius*
Baltimore Oriole – *Icterus galbula*

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A Three Year Survey of Aquatic Turtles in a Riverside Pond

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ABSTRACT

The results of a three-year trapping study of a turtle community in a small riverside pond near the Mississippi River in Jersey County, Illinois are reported. Five species were captured (in order of abundance) including the red-eared slider (*Trachemys scripta elegans*), the painted turtle (*Chrysemys picta*), the common musk turtle (*Sternotherus odoratus*), the common snapping turtle (*Chelydra serpentina*), and the spiny softshell (*Apalone spinifera*). We found that catch was affected by gear and time of year. Catches from fyke nets deployed in winter consisted of 68.4% *C. picta*, whereas the catch for baited turtle traps used in spring and fall consisted of 72.7% *T. scripta*. This probably reflects differences in behavior between the two species but it also suggests that trap bias may be an important factor in community studies. We used a recapture percentage index to judge trap bias for baited turtle traps. Catches made with baited turtle traps may have caused a 176% to 370% underestimate of abundance in *C. picta* and *S. odoratus*, respectively. We successfully tested a previously published model for *T. scripta* that predicts plastron length of melanistic males from the plastron length of three-year old females. The value from the model differed from the observed value by only 3.5 mm.

Key words: Turtle communities, trap bias, melanism, *Trachemys scripta, Chrysemys picta, Chelydra serpentina, Sternotherus odoratus*

INTRODUCTION

Studies of aquatic turtle communities are necessary to understand community composition and potential fluctuations in communtiy composition (Gibbons, 1997). Such studies, particularly long-term ones, are difficult and expensive and generally receive little funding support. Nonetheless they are needed to assess the impact of human activities on turtle communities (Smith et al., 2006). In Illinois, relatively few community studies have been reported (Dreslik et al., 2005), and none have been longer than 10 years.

In 1994, studies of aquatic turtle communities in backwater lakes of the Mississippi and Illinois Rivers began in west-central Illinois. Initially these studies were restricted to female nesting and their reproductive output (Tucker et al., 1998a, b; Tucker, 1999), but in 2001, trapping surveys were initiated and continue (Tucker unpublished). The present study involves a small pond created as a borrow pit adjacent to the Mississippi River in

southern Jersey County, Illinois. This pond is surrounded by human development (a marina, a golf course, and roadways). Surveys in the pond began in 2003 and concluded in 2005. Here we report these short-term results because the intensity of local human use precluded further study.

We also report the first test of a model for melanism in *Trachemys scripta* elaborated by Tucker et al. (1995). This model was developed from data collected on turtles from large river backwaters and has never been tested on turtles from other habitats. The model transcends sexual identity of the turtles by using data on three-year old females to predict plastron length in melanistic males.

MATERIALS AND METHODS

This study was conducted at a small borrow pond (ca 2 ha) located near the junction of Lockhaven Road and Illinois Route 100 in Jersey County, Illinois. The pond is near the Mississippi River and Piasa Creek but is separated from both by roadways, Illinois Route 100 and Lockhaven Road, respectively. Although emergent aquatic vegetation is present, the pond lacks submersed aquatic vegetation, other than filamentous green algae. Maximum water depth is 2 m, so the pond is permanent and does not normally dry during the summer.

We captured turtles using fyke nets (2003 and 2005) and baited turtle traps (2004). Four fyke nets were set on 20 November 2003 and four fyke nets were also used on 9 December 2005. Gutreuter et al. (1995) described these nets in detail. In 2004, we used six baited turtle traps (Legler, 1960) for a more intensive survey. We baited traps with fish carcasses and checked them daily. We deployed them from 3 May to 27 May (for 16 trap days) and from 15 September to 23 September (for six trap days).

We weighed each turtle with a spring balance to the nearest 10 g and measured plastron length, carapace length, width, and height with calipers to the nearest 1 mm. Sex was determined for specimens that had developed secondary sexual characteristics (Ernst et al., 1994). The few specimens whose sex could not be determined with certainty were classified as female. We marked turtles by drilling holes in the marginal scutes so each turtle had a unique combination of holes.

We tested the melanism model of Tucker et al. (1995) by comparing mean plastron length of three-year old females to mean plastron length of melanistic males. The model is $y = 150.71 + 0.21*x$, where x is the observed mean plastron length for three-year old females and y is the expected mean plastron length for melanistic males. To test the model, the observed mean plastron length for melanistic males is compared to the calculated value from the model. Age for the females was determined by examination of plastron annuli, which are a reasonably accurate estimate of chronological age in young *T. scripta* (Cagle, 1950; Tucker, 2002). Males range in the degree to which melanism is developed (Tucker et al., 1995), but they were only scored as melanistic when they had shell and skin melanism fully developed (stage-2 of Tucker et al., 1995).

Because not all turtle species respond similarly to traps (Ream and Ream, 1966), we used a percent recapture index to empirically compare our trap efficiency among species. This

index is R = [(T-I)/I]*100. Where R = recapture percentage, T = total captures for the species, and I = initial captures. The assumption is that if they are equally likely to be recaptured, they are equally likely to be caught initially. The index is sufficient for our preliminary study because it provides an estimate of trap bias. However, we have no measure of any bias in initial captures.

RESULTS

We captured 400 individuals of five species 977 times from 2003 to 2005 (Table 1). The red-eared slider (*Trachemys scripta elegans*) was the most frequently caught (Table 1) and had the highest recapture index. The recapture index for *T. scripta* was two to three times higher than for *Chrysemys picta*, *Sternotherus odoratus*, or *Chelydra serpentina*. We estimated turtle biomass to be at least 142 kg/ha (Table 1).

Fyke nets were used in winter trapping in 2003 and 2005, whereas baited turtle traps were used during the activity season in spring and fall of 2004. Both gears gave different impressions of the turtle community. More *C. picta* were caught in fyke nets and more *T. scripta* were caught in baited turtle traps (Table 2). In the fyke nets, *C. picta* made up 68.4% and *T. scripta* made up 15.7%, whereas in the turtle traps *T. scripta* made up 72.7% and *C. picta* made up 14.3% of the captures.

The sex ratio of species with multiple captures (omitting *Apalone spinifera* because we caught only a single female) approached 1:1 except for *Sternotherus odoratus*. Sex ratio was male skewed in *S. odoratus* with 71% of the turtles caught being males. Female *T. scripta* and *C. picta* females had longer carapaces than males (Table 3), and male *C. serpentina* had longer carapaces than females (Table 3). Means for all turtles on initial capture are given in Table 4.

We caught 29 stage-2 melanistic male *T. scripta*. These males had plastrons ranging from 164 mm to 211 mm (mean = 181.9 mm). The six females that were in their third season of growth averaged 131.7 mm in plastron length. The predicted melanistic male plastron length based on the model is 178.4 mm, which differed by 3.5 mm from the observed value.

DISCUSSION

In the region we studied, there are about 10 species of aquatic turtles that occur in aquatic habitats (Table 5, Ernst et al., 1994; Phillips et al., 1999; Tucker et al., 2001; Dreslik and Phillips, 2005). We found half of these in our small riverside pond. Typically these turtles associate in lacustrine habitats and none are riverine specialists (see Dreslik and Phillips, 2005, for a detailed classification), except for *Apalone spinifera* (Table 5). This is a remarkable finding given that our sampling was so limited. Generally our level of sampling was sufficient to detect only the most common species (Dreslik et al., 2005). Because riverine habitats such as the Mississippi River and Piasa Creek are in close proximity to our site, more extended sampling might have recovered more of the river turtles. Nonetheless, our results conform to turtle community that would be predicted from other analyses (Dreslik and Phillips, 2005).

Our captures using fyke nets and baited turtle traps differed remarkably, supporting the suggestion by Dreslik et al. (2005) that multiple gears should be employed when sampling turtle communities. These two gears function differently. Fyke nets have 15 m long leads that set perpendicular to the shore and that allows the net to work passively (Gutreuter et al., 1995). Turtles that swim into the lead are caught when they try to swim around the obstacle. Turtle traps use bait to attract turtles to the trap and require an effort by the turtle to get caught. However, the different turtle species caught could also be due to the use of fyke nets during the winter. Our data may reflect a difference in *T. scripta* and *C. picta* move during winter.

However, the fyke net sets may give a more representative sample because they are passive and do not require a behavioral response to work. Trap bias may be considerable as suggested by variation in our recapture percentage. *Trachemys scripta* was certainly the turtle most often recaptured and if the other three common turtles had the same recapture rates as *T. scripta*, we should have caught 137 *C. picta*, 141 *S. odoratus*, and 29 *C. serpentina*. If these values are substituted for those actually observed (Table 6), it is clear that the dominance of sliders in the population may be an artifact of the ways turtles respond to baits and traps. For instance, trap bias may have resulted in a 176% underestimate of *C. picta* abundance and an even more remarkable 370% underestimate for *S. odoratus*. Such potential bias compromises results of studies using raw trapping data (e.g., Dreslik et al., 2005; Dreslik and Phillips, 2005, and the studies they review). Our study is the only effort we know of that attempts to quantify trap bias for a turtle community.

Our findings for the first test of the model to predict the plastron length for melanistic males are noteworthy. This model was developed from data based on *T. scripta* caught in large backwater habitats of the Illinois and Mississippi Rivers (Tucker et al., 1995). Considering our small sample of females of the correct age (N = 6), the deviation of only 3.5 mm seems minimal. This suggests that this model may be applicable in other habitats in this region. It also suggests that the relationship between melanistic male size and age specific growth rates by female *T. scripta* first reported by Lovich et al. (1990) has considerable predictive power.

Another interesting finding is the roughly equal male to female sex ratio in *C. serpentina*. Considerable unpublished data developed by JKT at other Illinois sites in Jersey and Calhoun counties, suggest that sites close to roads generally have strongly male-biased sex ratios. This is thought to reflect removal of females for consumption by local inhabitants and loss of females to road kills. Consequently, we restricted our analysis to sexually mature turtles, those with a carapace length greater than 200 mm (Ernst et al., 1994). We collected only eight sexually mature turtles. Of these, six (75%) were males and two (25%) were females. This ratio is more consistent with others found for other sites along roadways in unpublished studies. Interestingly, we identified 4 of 5 immature turtles as females and only one small turtle as a male. This could reflect the difficulty of using the only known sexing method (see Ernst et al., 1994) on small turtles.

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Table 1. Turtles caught in a riverside pond in Jersey County, Illinois.

Species	Initial captures (percent females)	Percent of fauna	Recaptures N	R	Biomass (kg)
Trachemys scripta	270 (42.6)	67.5	471	174	197
Chrysemys picta	78 (50.0)	19.5	77	99	31
Sternotherus odoratus	38 (29.0)	9.5	18	47	10
Chelydra serpentina	13 (46.2)	3.3	10	77	43
Apalone spinifera	1 (100)	0.2	1	100	3
Total	400		577		284

R = recapture percentage.

Table 2. Initial captures of turtles in fyke nets and baited turtle traps.

Species	Fyke	Percent	Baited	Percent
Trachemys scripta	6	15.7	264	72.7
Chrysemys picta	26	68.4	52	14.3
Sternotherus odoratus	5	13.2	33	9.1
Chelydra serpentina	1	2.7	12	3.3
Apalone spinifera	0		1	0.6
Total	38		363	

Fyke net captures made in 2003 and 2005; baited turtle trap captures made in 2004; recaptures are excluded.

Table 3. Sexual dimorphism in carapace length in four species of turtles caught in a riverside pond in west-central Illinois compared using Kruskal-Wallis test.

Species	Mean carapace length		Chi square	*P*	df
	Male	Female			
T. scripta	136	179	47.55	0.0001	1
S. odoratus	112	103	1.13	0.2875	1
C. picta	133	142	6.70	0.0096	1
S. serpentina	255	155	5.89	0.0152	1

Table 4. Descriptive statistics for measures of size for five species of turtles caught in a riverside pond in west-central Illinois.

Species	Plastron length	Carapace length	Carapace witdh	Carapace height	Mass (g)	N
T. scripta	143 (48.6)	155 (52.3)	120 (35.6)	58 (18.9)	731 (592)	270
	58-237	62-253	56-1290	26-100	43-2700	
C. picta	128 (25.6)	138 (26.7)	101 (16.7)	47 (8.8)	393 (170)	78
	72-180	79-191	65-137	27-67	100-940	
S. odoratus	78 (12.5)	109 (17.5)	73 (10.3)	43 (6.4)	256 (79.4)	38
	17-90	24-128	20-83	13-54	3.1-410	
C. serpentina	158 (57.0)	209 (81.6)	179 (69.2)	88 (33.4)	3274 (2665)	13
	63-234	80-322	72-287	36-129	150-8275	
A. spinifera	230	313	230	83	3398	1

Measures of length, width, and height are in mm; mass is in g. Recaptures are excluded. Mean (standard deviation) is given on top line; range (maximum and minimum) is given below.

Table 5. Species of aquatic turtles known to occur in west-central Illinois and their preferred habitats compiled from Ernst et al., 1994 and Dreslik and Phillips, 2005.

Species	This study	Preferred habitat
Common snapping turtle (*Chelydra serpentina*)	yes	pond/river
Smooth Softshell (*Apalone mutica*)		river
Spiny softshell (*Apalone spinifera*)	yes	river
Common musk turtle (*Sternotherus odoratus*)	yes	pond/river
Painted turtle (*Chrysemys picta*)	yes	pond/river
Red-eared slider (*Trachemys scripta elegans*)	yes	pond/river
Cooter (*Pseudemys concinna*)		river
Common map turtle (*Graptemys geographica*)		river
False map turtle (*Graptemys pseudogeographica*)		river
Ouachita map turtle (*Graptemys ouachitensis*)		river

Table 6. Use of recapture percentage index to normalize number of turtles of four species given recapture percentages equal to that calculated for *Trachemys scripta* for other three species.

Species	Unadjusted		Adjusted for recapture	
	Total	%	Total	%
T. scripta	270	67.7	270	46.8
C. picta	78	19.5	137	23.7
S. odoratus	38	9.5	141	24.4
C. serpentina	13	3.3	29	5.1
Total	399		577	

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Distribution of the Long-tailed Weasel (*Mustela frenata*) in Illinois

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ABSTRACT

Knowing the geographic distribution of any species is an important first step toward understanding its ecology. Long-tailed weasels (*Mustela frenata*) are secretive and difficult to detect, so little is known about their distribution in Illinois. To fill this gap in the knowledge, we solicited information from museum curators about the sites where long-tailed weasel specimens were collected in Illinois and surveyed biologists and recreational trappers to document locations of where they had seen or captured long-tailed weasels. We present an updated map of long-tailed weasel distribution, documenting presence in at least 60 of the 102 counties in Illinois. Long-tailed weasels were seen or captured in a variety of habitats, including fields, forests, and forest edges. Most survey respondents considered long-tailed weasels to be relatively scarce. The information we have collected more than doubles the number of counties where long-tailed weasels are known to exist, and indicates that this small carnivore is widely distributed throughout the state.

INTRODUCTION

Knowing where a species can be found is one of the most basic steps in understanding its ecology. The geographic distributions of species have been used to better understand the biotic and abiotic factors that limit populations (Case and Taper, 2000), as well as to understand patterns and process of extinction (Lomolino and Channell, 1995). On a more practical level, researchers have overlaid distribution maps of multiple species to provide coarse maps of biological diversity (Scott et al., 1993). Finally, knowing the distribution of a species can simply allow biologists to focus their attempts to study it in areas where it is known to occur. However, information about the distribution of a species must often be gathered from a variety of sources.

Records obtained by museum collections, surveys, and personal interviews can be used to characterize the distribution of a species. Each method has its weaknesses, but when combined they can provide a more complete picture of a species' distribution. In some cases, collection locations are known for museum specimens. However, museum collections may hold few specimens of a given species and therefore do not provide an accurate representation of species distribution. Surveys have also been used by agencies and

researchers to determine the distributions of long-tailed weasels and other species (Proulx and Drescher, 1993; Groves, 1988). Surveys can provide more recent information about a large area without intensive effort, but response is not guaranteed and species identification may be questionable.

Weasel species in general are ecologically important yet difficult to study. In Scandinavia, weasels appear to drive population cycles of voles and lemmings (Hanski et al., 1991; 2001). In New Zealand, the introduced stoat (*Mustela erminea*) threatens native fauna populations, necessitating management to control stoat abundance (Murphy et al., 1998). Weasels in Europe and North America can be important nest predators affecting avian production (Dunn, 1977; Fleskes, 1988). However, little is currently known about the status and ecology of the long-tailed weasel (*M. frenata*) in North America as compared to other furbearer species and to weasels in other geographic areas (Sheffield and Thomas, 1997), probably due to their secretive nature and the lack of standardized methods for their detection and capture.

The distribution of the long-tailed weasel in Illinois was most recently described by Hoffmeister (1989), based on museum specimens and published records. He found records of long-tailed weasel occurrence in 27 Illinois counties, primarily in the northern half of the state with only a few specimens collected in southern counties. However, Hoffmeister (1989) based his assessment of long-tailed weasel distribution on a small sample size of specimen records, so the species may be more widely distributed than his distribution map would suggest. Our objective is to update the known distribution of long-tailed weasels in Illinois based on a larger sample of museum specimens as well as sightings and captures reported by biologists, trappers, and hunters.

METHODS

We attempted to contact 182 mammal collection curators in the U. S. to compile records of long-tailed weasel specimens from Illinois. We searched the World Wide Web for online collections and requested additional information from collection curators when detailed information was not available online. We also searched for collections held by universities and state agencies. We contacted curators by telephone and email, requesting all available information concerning long-tailed weasels in their collections that originated in Illinois, with particular interest in the collection location. If a response was not received from a curator after 3 weeks, we sent out a second email or telephone call repeating the information request.

To most effectively gather information concerning sightings and captures of long-tailed weasels in Illinois, we developed surveys to be sent to recreational trappers and to biologists throughout the state. On 5 December 2003, we sent surveys to 117 trappers, who had participated in the 2002-2003 Illinois Department of Natural Resources trapper survey and reported having seen or captured a weasel (of any species) in the past 3 years (Miller et al., 2003), plus 3 hunters. On 3 September 2004, we sent surveys to 130 biologists working in Illinois at research universities, state and federal agencies, and non-governmental organizations. The survey asked if the recipient had seen or captured any long-tailed weasels within the past 5 years and, if so, to report the location and other information about the event (e.g., habitat type). Due to differences between observers,

length of observation time, and distance at which a sighting occurred, not all reports of weasel sightings are equally reliable. Therefore, participants were asked to report their confidence in the identity of their sighting. Those who reported having seen or captured a weasel were sent a follow-up letter and a map to more accurately mark the location of these events. Survey methods were approved by the Southern Illinois University Carbondale Human Subjects Committee.

RESULTS

We contacted 126 curators, only 18 of which indicated that their collections contained long-tailed weasels originating from Illinois, totaling 181 long-tailed weasel specimens. We mapped 179 specimens taken from 44 of the 102 counties in Illinois (Figure 1A); the other 2 records were collected in central Illinois but the specific counties they came from were unknown. Of the 181 specimen records, 142 listed the sex of the specimen with 105 (74%) males and 37 (26%) females. Years in which weasels were collected ranged from 1864 to 2003. Of those specimens for which measurements were reported (n = 24), 4 were female, 19 male, and 1 unknown. The average (± SD) total body length was 363 ± 45 mm for males and 284 ± 13 mm for females; average tail length for males was 115 ± 19 mm for males and 89 ± 13 mm for females; and average hind foot length was 40 ± 4 mm for males and 34 ± 2 for females.

Of the 121 surveys sent to trappers and hunters, 11 were returned undeliverable, and we received 37 responses (34% response rate). Respondents reported having trapped recreationally in 34 counties (Fig. 1B). Thirteen reported seeing or capturing ≥1 long-tailed weasel in the last 5 years, with a total of 32 sighting locations and 30 capture locations (Fig. 1B). Twenty-one of these locations were in counties where there was ≥1 record of a museum specimen. Of the trappers that reported weasel sightings, 16 were very confident, 3 were confident, and 1 was somewhat confident that what they saw was a long-tailed weasel.

Of the 127 surveys sent to biologists, 3 were returned undelivered and we received 52 responses (42% response rate). Twenty biologists reported either seeing or capturing ≥1 long-tailed weasel in the last 5 years, with a total of 33 weasel sightings and 7 captures (Figure 1C). Twenty-three of these locations were in counties where there was ≥1 record of a museum specimen. Of the biologists who reported weasel sightings, 11 were very confident, 4 confident, and 3 somewhat confident that what they saw was a long-tailed weasel. Two reported sightings in east-central Illinois could not be mapped, because the counties in which they were seen were uncertain.

Combining data from all museum specimen locations and capture/sighting locations from the surveys, long-tailed weasels were found in 60 of the 102 counties in Illinois (Figure 1D). These counties are fairly evenly dispersed throughout the state and are not clumped in any one portion of the state, although the number of reports of weasel occurrence in these counties varied from 1 to 49.

Of the trappers and biologists that reported seeing or capturing a long-tailed weasel, we received 69 descriptions of the type of habitat present at sighting or capture locations. Some participants described >1 type of habitat, so our results sum to more than 69

responses. Twenty-four of the participants indicated that they saw or captured weasels near a permanent or intermittent water source such as a lake, stream, ditch or drainage. Thirty participants mentioned fields in their descriptions of habitat: 17 reported weasels in old fields, 1 in an agricultural field, and 12 were not specific as to the type of field. Fifteen participants described weasels using a habitat edge: 4 reported a forest/old field edge, 2 a forest/agricultural field edge, 5 a forest/old field/ agricultural field edge, and 4 were not specific about the type of edge. Ten participants saw or captured long-tailed weasels in forested areas, 6 in brushy or early successional forest areas, and 5 near human dwellings of development and 2 along fence rows.

DISCUSSION

Species distribution maps for rare or secretive species are likely to be very sensitive to sample size. Our search for long-tailed weasel specimens resulted in 181 records, which exceeds the 48 examined by Hoffmeister (1989) and the 12 additional records he found in the literature. From the museum specimens for which we were able to find records, we documented weasel occurrence in all counties where Hoffmeister found records, plus 17 additional counties. Thus, an updated review of museum specimens alone increased the known number of counties with long-tailed weasels from 27 to 44.

It is difficult to accurately determine long-tailed weasel distribution based on surveys, but surveys indicate areas that should be investigated for weasel presence using other methods. This difficulty is because weasels are not distributed evenly in all habitats, population levels are not static (King, 1989), and survey recipients have varying ability to recall events and identify species. However, reports from trappers and biologists responding to the surveys were often supported by museum specimens collected in the same counties, adding to the credibility of their report. Many biologists and trappers keep very detailed records of trap sites used and capture information, which aids in recalling this information, and they have had more training in identifying these species than the general public.

The use of surveys to determine geographical distribution of a species could be improved by increasing the number of respondents. We surveyed a small sample of the recreational trappers in the state and received completed surveys from only one-third of this group, who trapped recreationally in only about one-third of the counties in Illinois. Within the 34 counties with trapping, there were reports of captures or sightings in 23. Weasel sighting information was obtained from trappers in reference to only 2 counties where trapping was not reported to occur. Therefore, the trappers we surveyed were only able to provide limited information on weasel occurrence in 36 of the 102 Illinois counties. By surveying a greater number of trappers, information could be obtained from recreational trappers in all 102 Illinois counties.

Although reports of long-tailed weasel occurrence are few, it is important to note that few recreational trappers target the long-tailed weasel (Richter, 2005), so low capture success is expected for this species. Also, because weasels have small home ranges compared to many furbearer species (Quick, 1944; 1951; DeVan, 1982; Gerhing and Swihart, 2004) they may not regularly cross roads where they would be more visible. Another reason weasels may rarely be seen is that they often hunt and rest in underground burrows and

dens (King, 1989). For these reasons it is not surprising that there were few reports of weasel sightings.

Previously, the long-tailed weasel was documented to occur primarily in the northern portion of Illinois (Hoffmeister, 1989). However, we compiled records of museum specimens and survey reports of captures and sightings from 60 of the 102 Illinois counties, strongly suggesting that the long-tailed weasel presently occurs statewide. Although weasels could have expanded into these areas in recent years, it is more likely that weasels previously existed in many of these areas without detection. Based on its historic range throughout the U.S., the long-tailed weasel occurs in states immediately surrounding southern Illinois such as Arkansas, Kentucky, Indiana, Missouri, and Tennessee (Hall, 1951; Simms, 1979; King, 1989). More recent studies also have documented weasels or weasel sign in Kentucky (DeVan, 1982), Indiana (Gehring and Swihart, 2003; 2004), east central Illinois (Rosenblatt et al., 1999) and central Illinois (Brawn et al., 2002), revealing long-tailed weasel presence near southern Illinois.

As habitat generalists, it is likely that long-tailed weasels occur in many areas throughout Illinois. Long-tailed weasels are reported to use a variety of habitat types (Fagerstone, 1987; Hoffmeister, 1989) as long as there is a nearby water source (Hall, 1951; King, 1989). Illinois offers a variety of suitable habitats. Much of Illinois is agrarian with fence rows and corridors for movement (Neely and Heister, 1987). There are also large tracts of deciduous forests such as the Shawnee National Forest (Neely and Heister, 1987), open woodlands, old fields such as lands put into the Conservation Reserve Program (Isik and Yang, 2004) and reclaimed coal strip mines, and some urban areas. Illinois also offers a varied prey base with voles (*Microtus* spp.) and mice (*Peromyscus* spp., *Ochrotomys nuttalli*, *Mus musculus*, and *Zapus hudsonius*) found throughout the state, as well as other species of suitable prey for the long-tailed weasel (Hoffmeister, 1989).

With effort, the long-tailed weasel will probably be detected in many of the remaining 43 counties in Illinois. Surveying for weasel presence could best be accomplished with effort concentrated at sites with high prey density near permanent water sources. Track tube surveys (King and Edgar, 1977; Murphy et al., 1998; 1999; Graham, 2002; Richter, 2005) or trapping (Gehring and Swihart, 2004; DeVan, 1982) would be the most useful techniques to determine weasel presence, with trapping providing the most positive form of identification. Information gained from these surveys would enhance existing knowledge of long-tailed weasel distribution. Information about sites where weasels are not present or abundance is relatively low is as important as information about areas where abundance is relatively high. With this knowledge, biologists can investigate habitat characteristics absent in those areas where weasels do not occur or abundance is low and attempt to improve them. This information would help to monitor future changes in this species' range and offer insight into what factors may cause this species to increase or decline.

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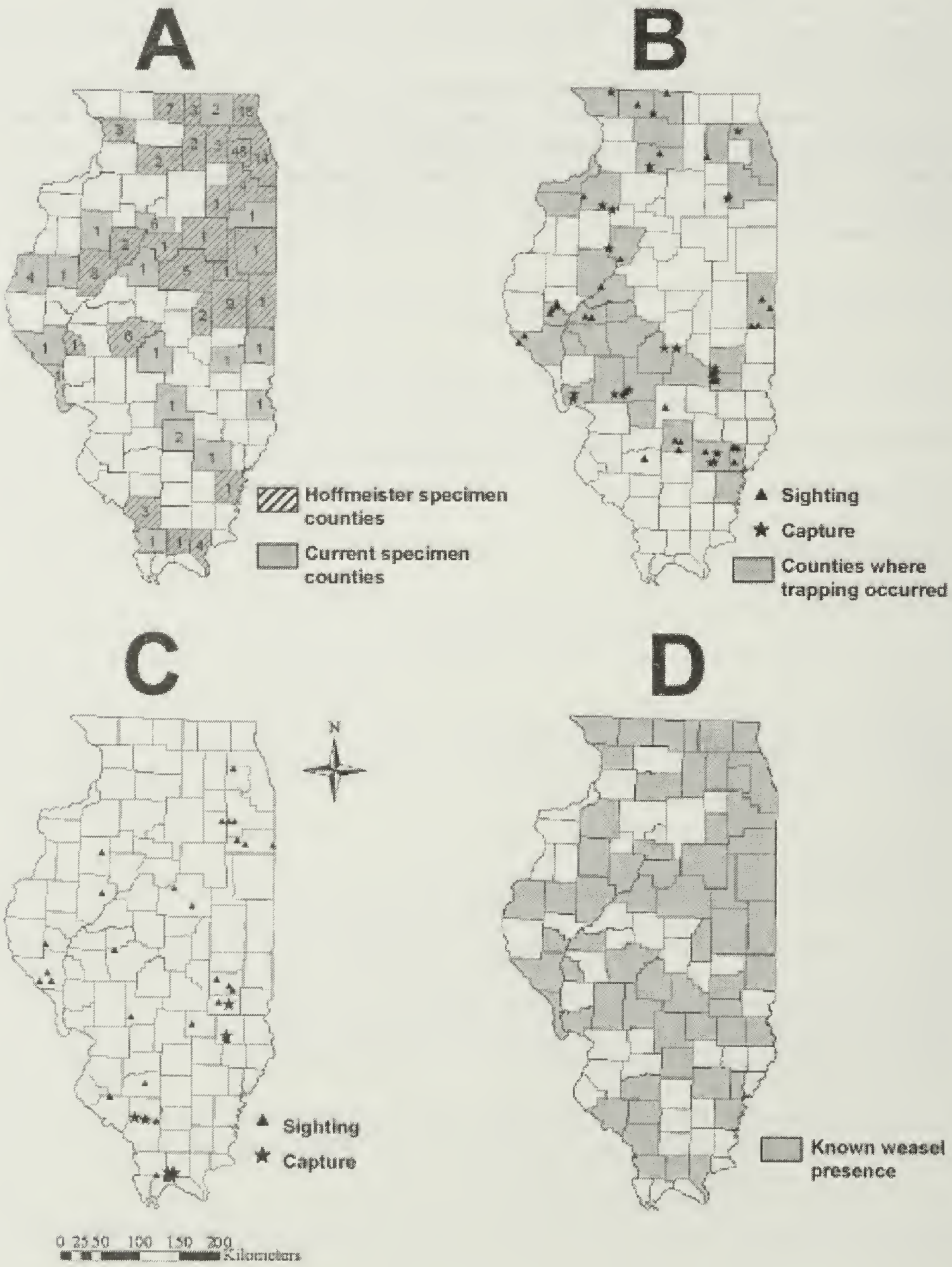
Figure 1. Distribution of long-tailed weasel records in Illinois. (A). Number of long-tailed weasels collected as museum specimens from each Illinois county, 1864-2003, with comparison to counties where Hoffmeister (1989) reported long-tailed weasel specimens collected. (B and C) Illinois counties where (B) trapper survey participants and (C) biologists reported sightings and captures of long-tailed weasels, 1999-2003. (D) Illinois counties where ≥1 long-tailed weasels were collected as museum specimens, or sighted or captured by a trapper or biologist.



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Nest Success of Giant Canada Geese in Southern Illinois

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ABSTRACT

Giant Canada Geese (*Branta canadensis maxima*) were released by the Illinois Department of Conservation (IDOC) in west-central Illinois in the late 1960's and in southern Illinois in the mid-1980's in an effort to re-establish resident flocks of Canada geese in Illinois for their aesthetic value and harvest potential. Illinois Department of Natural Resources Giant Canada Goose surveys, however, indicate a density three times greater in the northern 2/3 of the state than in the southern 1/3 of the state. To determine if variation in nest success explains the difference in Giant Canada Goose nesting density between northern and southern Illinois, we estimated nest success of geese nesting in various wetland habitat types in southern Illinois, then compared those estimates to estimates from other studies conducted in central and northern Illinois. In 2003, 181 nests were located and in 2004, 221 nests were located providing 402 total nests for the study. The most parsimonious model included a covariate of clutch initiation date and habitat type, but daily nest survival was held constant between years, and among days of the breeding season, and locations. Nest success for a nest initiated on the mean initiation date over all study sites and years combined was estimated to be 61% (SE = 4.8%). Nest success in our study was greater than or equal to estimates of nest success in other regions of Illinois indicating variation in nest success is not leading to lower population densities of Giant Canada Geese in southern Illinois.

INTRODUCTION

Giant Canada Geese (*Branta canadensis maxima*) were released by the Illinois Department of Conservation (IDOC) in west-central Illinois in the late 1960's and in southern Illinois in the mid-1980's in an effort to re-establish resident flocks of Canada Geese in Illinois for both their aesthetic value and harvest potential. Estimates of breeding densities of Giant Canada Geese in Illinois, however, indicate a nesting density three times greater in the northern 2/3 of the state than in the southern 1/3 of the state (Illinois Department of Natural Resources unpublished goose survey data). Variation in population density between the 2 regions could be due to variation in immigration, emigration, productivity, or mortality.

Variation in productivity of most waterfowl species is most sensitive to variation in nest success (e.g., Hoekman et al. 2002). Kadlec and Smith (1992) suggested differences in

habitat type among geographic regions may be the principle factor affecting variation in nest success because habitat dictates: (1) available nesting sites, (2) nutrients available prior to laying and during incubation, (3) behavior of the breeding pair, and (4) protective cover. Habitat differences can influence predator abundance and concealment from predators, both of which impact nest success (Hines and Mitchell 1983, Johnson et al. 1989). Because of the considerable variation in habitat structure among regions of the state, variation in nest success between northern and southern Illinois may lead to differences in regional Canada Goose productivity. In fact, in previous studies, estimates of nest success tended to be higher in southern Illinois (73% SE = 4%) than northern (44%, SE = 1.5%) or central (63% SE = 2%) Illinois. These results indicate low nest success is not the cause of the difference in population density between regions of the state (Butler 1987, Lawrence 1987, Cline 2004). Despite these results, management strategies designed to increase nest success (e.g., building nesting structures and islands) have been implemented to increase productivity of Giant Canada Geese in southern Illinois. An argument supporting the continued use of these practices is the method used to estimate nest success in central and southern Illinois (termed apparent nest success), is inherently biased high (Mayfield 1961). Furthermore, reclamation of the surface mines on which most of the nests were located in southern Illinois was completed within 5 years of the initiation of the study, thus, the successional stage of the vegetation in those habitats has likely advanced considerably since the original study; leading to potential changes in nest success. Because of the potential bias associated with the methodology originally used to estimate nest success in central and southern Illinois, and the likely changes in the successional stage of the habitat in southern Illinois, we believe additional information regarding variation in nest success is needed to determine if management actions designed to increase productivity by increasing nest success is an appropriate strategy.

To determine if variation in nesting densities among regions of the state may be at least partially explained by variation in nest success and determine the potential of increasing Giant Canada goose productivity in southern Illinois by implementing management strategies that increase nest success, we estimated current nest success of geese nesting in a variety of habitat types in southern Illinois. We then compared those findings to previous studies of goose productivity in central and northern Illinois.

METHODS

Study Site

Our study sites included minelands, parklands, and reservoirs; habitats that are commonly found in southern Illinois. A study site was classified as parklands if > 50% of the upland habitat was mowed and the mowed area was larger than the surface area of any associated waters (e.g., city parks). A study site was classified as reservoir if < 50% of the upland habitat was mowed and the mowed area was smaller than the surface area of any associated waters. Minelands were classified as any habitat associated with reclaimed surface mines. Study sites that were classified as reservoirs included Baldwin Lake, an 809 ha reservoir located north of the town of Baldwin, Illinois, on the border of Randolph and St. Clair Counties and Kinkaid Lake, a 1115 ha reservoir located west of Murphysboro, Illinois, in Jackson County. The lone parkland site was the DuQuoin State Fairgrounds located in Perry County east of DuQuoin, Illinois.

Reclaimed surface mines are distributed widely throughout southern Illinois and were included as a separate category because of the inherent physical traits associated with mine reclamation. Surface mines are categorized as either "pre-law" or "post-law." Pre-law surface mines are those where mining was completed prior to the first Illinois reclamation law in 1962 (Lueth 1986). Pre-law mines are characterized by numerous spoil ridges, steep and elongated islands, deep lakes, small ponds between spoil ridges, and dense forest cover (Lueth 1986, Butler 1987). Pyramid State Park, a 809 ha mine located southwest of Pinckneyville, Illinois, in Perry County and purchased by the Illinois Department of Natural Resources for recreational use was the lone a pre-law surface mine included in our study.

Post-law mine reclamation initially required spoil ridges to be leveled off to a minimum width (~ 3m), but later reclamation laws required that spoil ridges be graded to the original land contour and restored to its original production capability (Lueth 1986:3). Post-law mines are characterized by deep lakes, small ponds, rounded islands, limited tree growth, fields composed of grasses and herbaceous plants, and agricultural fields (Lueth 1986, Butler 1987). The study sites classified as post-law minelands include: Burning Star #5, a 2,025 ha mine located east of DeSoto, Illinois in Jackson County; Captain-Hunter, a 6,475 ha sub-unit of Pyramid State Park, located southeast of Cutler, Illinois, in Perry County; River King #3 a 728 ha mine located northeast of New Athens, Illinois, in St. Clair County; and a 200 ha portion Sahara #6, located west of Harrisburg, Illinois, in Saline County. The River King #3 and Sahara #6 mines were included in earlier studies of giant Canada goose populations in southern Illinois, following initial reintroduction in the early 1980's (Lueth 1986, Butler 1987).

After our first field season, efforts were focused on those study sites with the highest nesting densities of Giant Canada Geese, thus, Pyramid State Park was dropped from our study. This was done to increase the number of web-tagged goslings that were used in a different component of the study.

Data Collection

Nest Searches. Nest searches were conducted weekly at each study site, beginning the first week of March and continuing through the end of the nesting season (approximately the middle of May). We visually located nests with a shore-based spotting scope by observing females sitting on nests or pairs displaying nesting activities, on foot by walking potential nesting areas, or by boat to survey potential nesting areas. A nest was considered to be active if at least one viable egg was found within the nest bowl upon the first encounter, additional eggs were found upon subsequent encounters, or incubating activities (i.e. lining the nest bowl with down feathers, female actively incubating the clutch, or pair defending the clutch) were observed. Each nest was assigned an alphanumeric code (site and nest number), which was recorded on an aerial photograph of each site. During the 2004 field season, nests in high-density nesting areas were marked with a numbered stick to avoid nest misidentification.

Nest Monitoring. Nests were visited once a week until hatching, nest loss, or abandonment. The age of the clutch within each nest was determined by egg flotation, allowing us to also estimate the projected hatch date of each clutch (Westerkov 1950, Alberico 1995, Walter and Rusch 1997). During times of expected hatch, some nests were visited twice a

week to increase the chance of observing goslings in the nest bowl. Nests were classified as successful if one or more eggs hatched.

Statistical Analysis

Nest Success. We used Dinsmore's model in Program MARK to determine if the data indicated nest survival varied by study site, nesting habitat, age of nest when first located, year, date, and initiation date (White and Burnham 1999, Dinsmore et al. 2002). Dinsmore's model in Program MARK was chosen because it allows us to relax some of the assumptions associated with the Mayfield Method (White and Burnham 1999, Dinsmore et al. 2002). For example, the Mayfield Method is based on the assumption of nest survival being constant over time, whereas Dinsmore's model in Program MARK generates daily survival estimates, which allow for modeling across multiple groups, such as age of nest when first located and initiation date (Dinsmore et al. 2002, White pers. comm. 2005). The quasi-likelihood parameter (*c*-hat) was calculated by dividing deviance by the degrees of freedom of the saturated model. The *c*-hat was used to adjust for over-dispersion of the data for each model, and to obtain a quasi-Akaike's Information Criterion (QAICc) in order to determine which model best fit the nesting data from a model set that included models with all main factors and two-way interactions. The daily nest survival estimated from the most parsimonious model was multiplied exponentially by a power equal to the sum of average total clutch size and a twenty-eight day incubation period (for this study that value was equal to 33) to calculate the nest success for each study site (Brakhage 1965, Cooper 1978, Coluccy 2001).

$$\text{Nest Success} = \text{Daily Survival Estimate}^{(\text{Average Total Clutch Size} + \text{Incubation Period})}$$

To estimate overall nest success for the study, the most parsimonious model was chosen from the models which did not allow nest success to vary by individual study site or habitat type, and the above equation was used. The Delta method was used to estimate the variance for estimates of nest success (Seber 1982:7).

RESULTS

In 2003, 181 nests were located and in 2004, 221 nests were located providing 402 total nests for the study. All nests were found on islands or peninsulas and no artificial nest sites were used even though they were available in both years of the study. The first nest located in 2003 was initiated on March 11 and the first nest located in 2004 was initiated on March 4. The last nest was initiated on April 22 in 2003 and on April 27 in 2004. Peak initiation was March 25 in 2003, March 15 in 2004, and March 24 for both years combined. The peak hatch date was April 24 in 2003, April 21 in 2004, and April 24 for both years combined.

Nest Survival and Success. The value for *c*-hat was calculated as 3.51 for the global model indicating moderate over-dispersion, therefore, a variance inflation factor of 3.51 was applied to all estimates of sampling variance and model selection criteria. The most parsimonious model included a covariate of clutch initiation date and habitat type (i.e., mineland, parkland, and reservoir) but held nest survival constant across all other parameters (Table 1). Daily nest survival was estimated to be greater for the parkland habitat than for the mineland or reservoir habitat (Table 2). Using the most parsimonious

model that held nest survival constant among habitat types and study sites (the second model in Table 1) we estimated daily survival rate of nests with an average initiation date to be 0.985 (SE = 0.003) and nest success to be 61% (SE = 4.8%). Nest depredation was the cause of > 98% of the nest failure with nest abandonment (likely due to wave action on one reservoir) accounting for the other approximately 2%.

DISCUSSION

For an unknown reason, the current nesting density of Giant Canada Geese in southern Illinois is low relative to the northern 2/3 of the state. The density of a population is primarily determined by the product of its various vital rates. One vital rate that has been identified as having a large influence on the productivity of waterfowl populations is nest success. Therefore, variation in nest success among regions of Illinois may help explain variation in nesting density, and thus, management strategies designed to increase nest success may be appropriate when attempting to increase nesting density of Giant Canada Geese in southern Illinois. Our estimate of nest success, 61% (SE = 4.8%), however, was higher than that from a study conducted in northern Illinois (44% SE = 0.8%, Cline 2004), and similar to a study conducted in central Illinois (63% SE = 2%, Lawrence 1987). While it should be noted, apparent nest success was used for the study in the central Illinois, thus, the estimate is likely biased high (Mayfield 1961); unbiased estimators were used for both Cline's (2004) study in northern Illinois and our study.

For this study, we were unable to locate nests in habitats other than islands or peninsulas, and most noticeably, no artificial nesting sites (i.e. tubs, tires, hay bales, etc.) were used despite their availability during both years of the study. Nest success is generally higher when islands or nesting structures are chosen as nesting sites (Ewaschuk and Boag 1972, Lueth 1986, Butler 1987, Lawrence 1987, Coluccy 2001). Even when we compare nest success of nests found only on islands or peninsulas between regions of Illinois, however, it appears nest success is as high or higher in southern Illinois (61%, SE = 4.8%) than northern Illinois (48%, calculated from Cline 2004's estimates of daily nest survival).

Nest success has been found to be negatively impacted by predation, abandonment, dump nesting, weather, overcrowding, and poor nest site location (Hines and Mitchell 1983, Lueth 1986, Johnson et al. 1989, Kadlec and Smith 1992). In our study, almost all nest failure (> 98%) was attributed to nest depredation, whereas, in northern Illinois, predators played a lesser role causing only about 60% of he nest failures while nest abandonment (approximately 20%), and nest flooding (approximately 8%) were also important. We hypothesize causes of nest failure differed between the regions due to differences in predator density and density of nesting geese. Almost all nest locations from our study were in rural settings relative to nests located in Cline's (2004) study in northern Illinois. We hypothesize the more rural conditions found in southern Illinois likely supported a higher density of goose nest predators leading to greater nest predation. This hypothesis is supported by the variation in nest success observed among habitat types in our study (Table 2). In our study, nest failure was substantially higher in more rural habitats (minelands and reservoirs) than in the more urban parkland habitat. Furthermore, we hypothesize the reason other factors commonly found to impact nest success (i.e. nest abandonment and flooding) were unimportant in our study was due the low nesting density in southern Illinois relative to northern Illinois. Most nest abandonment occurs from

conflicts between neighboring nesting pairs (Kadlec and Smith 1992). We suggest nesting density in southern Illinois is inadequate to cause substantial conflict between neighboring pairs, thus little nest abandonment occurs. Also, we hypothesize low nesting density relative to other regions allows geese to select nest sites with little likelihood of flooding, preventing nest failure due to flooding. This hypothesis is supported by our observation that, in contrast to most areas where artificial nesting structures exist, artificial nesting structures were unused on our study, indicating that more natural secure nesting sites were available. Alternatively, Kadlec and Smith (1992:597) suggested that the use of artificial nesting structures "may be a learned trait, resulting in low occupancy rates until a local population accustomed to the structures is built up." Indeed, the vast majority of artificial nesting structures available during this study had only been available for one to two years. Thus, it is possible that the Canada Geese nesting on study sites with artificial nesting structures had not yet "learned" how to efficiently use them.

Despite the apparent high rate of nest failure due to nest predation in southern Illinois relative to northern Illinois, nest success in southern Illinois (61%, SE = 4.8%) appears to be greater than nest success in northern Illinois (44% SE = 0.8%) and similar to the potentially biased estimate of nest success in central Illinois (63%, SE = 2%). Therefore, low nest success is likely not the explanation for the low population density of Giant Canada Geese in southern Illinois relative to other regions of the state. Even in regions of the country where tools such as artificial nesting platforms have been used extensively as a management strategy to increase nest success, nest success rates substantially greater that 61% have rarely been achieved (see Coluccy 2001 for review), thus artificially increasing nesting habitat in southern Illinois would likely have little effect on productivity of Giant Canada Geese. In addition, if other components of productivity such as gosling growth (Sertle 2005) are more limiting, increasing nest success will likely have little impact on the population. These results indicate management strategies designed to increase nest success will not likely achieve the goal of increasing nesting density of Giant Canada Geese in southern Illinois.

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Table 1. Comparison of nest survival models using Dinsmore's model in Program MARK including all models with a $QAIC_c$ of < 25.

Model	Deviance	*K*	$QUIC_c$	$\Delta QAIC_c$	w_i
Initiation Date + Habitat	232.82	4	240.82	0.00	0.83
Initiation Date	240.94	2	244.94	4.12	0.11
Site + Initiation Date	228.95	9	246.97	6.15	0.04
Year + Site + Initiation Date	228.94	10	248.97	8.15	0.01
Year + Site + Initiation Date + Age of Nest	228.88	11	250.91	10.09	0.00
Year * Site * Initiation Date	216.45	18	252.54	11.72	0.00
Site * Initiation Date	226.96	14	255.01	14.19	0.00
Constant	259.06	1	261.07	20.24	0.00
Calendar date	235.56	15	265.62	24.80	0.00
Site	249.86	8	265.87	25.05	0.00

Year = 2003, 2004.
Habitat = Mineland, Parkland, Reservoir.
Age of Nest = The age of the nest at the time of discovery in days.
Initiation Date = The Julian date on which the clutch was believed to have been initiated.
Calendar Date = Allowed survival to vary by date.
Site = Baldwin Lake, Captain-Hunter, Sahara #6, Burning Star #5, Pyramid State Park, Kinkaid Lake, River King #3, DuQuoin State Fairgrounds.
K = The number of parameters.
w_i = The model weight.

Table 2. Percent nest success ± standard error (SE) from the second model in Table 1.

Study Site	No. of Nests	Daily Nest Survival	Nest Success
Reservoir	256	0.982 ± 0.003	52% ± 2%
Mineland	106	0.984 ± 0.005	56% ± 3%
Parkland	40	0.998 ± 0.002	95% ± 1%
Southern Illinois	402	0.985 ± 0.003	61% ± 5%

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Rediscovery of the Freckled Madtom *Noturus nocturnus* Jordan & Gilbert in the Des Plaines River, Illinois

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ABSTRACT

An interesting catfish, the freckled madtom (*Noturus nocturnus*), was collected in the Des Plaines River just above its confluence with the Chicago Sanitary and Ship Canal on 16 May 2005. Measuring 86.3 mm in standard length and weighing 14.6 grams, this is the first time a freckled madtom has been collected at a close proximity to Chicago in 100 years. It is possible that the freckled madtom was present all along, but was overlooked due to its difficulty to collect, naturally sporadic occurrence (Pflieger 1975, Mettee et al. 1996), and misidentification. It is the hope that this can be interpreted as an improvement in water quality, and if so, other native fishes may possibly regain their former ranges closer to Chicago in the future.

Key Words: freckled madtom, *Noturus nocturnus*, Des Plaines River, identification, recolonization, water quality

INTRODUCTION

Madtoms are a subgroup of the North American bullhead catfish family Ictaluridae. These small catfishes, usually less than a few inches long, comprise the genus *Noturus*. There are currently 28 named species of madtoms throughout eastern North America (Burr et al., 2005), seven of which are known from Illinois and four from the Chicago Region (which can roughly be defined as a 100-mile radius around the city). They live along the bottom, usually hiding among rocks, logs, vegetation and detritus. Madtoms are most active at night when they feed on aquatic insect larvae and other small organisms. Because of their small size and reclusive nature, anglers and wildlife observers rarely see madtoms. They are also commonly confused with bullheads and other juvenile catfishes.

Freckled madtoms are found in medium-sized creeks to large rivers. The preferred habitats are riffles and nearby pools with slow to swift current, with substrates of boulder, cobble, gravel, sand, silt, woody debris and detritus (Pflieger, 1975; Smith, 1979; Burr and Mayden, 1982; Etnier and Starnes, 1993; Mettee et al., 1996; F.M. Veraldi, pers. observ.). The freckled madtom may also be found among root masses and undercut banks, as well as discarded bottles, cans, and other foreign debris (Burr and Mayden, 1982). It is found in clear to moderately turbid waters (Smith, 1979; Burr and Mayden,

1982; Page and Burr, 1991; Etnier and Starnes, 1993). The majority of the freckled madtom's diet is composed of aquatic insect larvae, but it will consume other invertebrates, such as crustaceans (Burr and Mayden, 1982; Cross and Collins, 1995).

RECENT COLLECTIONS

The known range of the freckled madtom extends from eastern Texas to western Alabama and from central Indiana to southeastern Iowa (Pflieger, 1975; Etnier and Starnes, 1993; Mettee et al., 1996). The northernmost range of this species reaches northeastern Illinois (Page and Burr, 1991) within the Illinois River system and most recently the Des Plaines River.

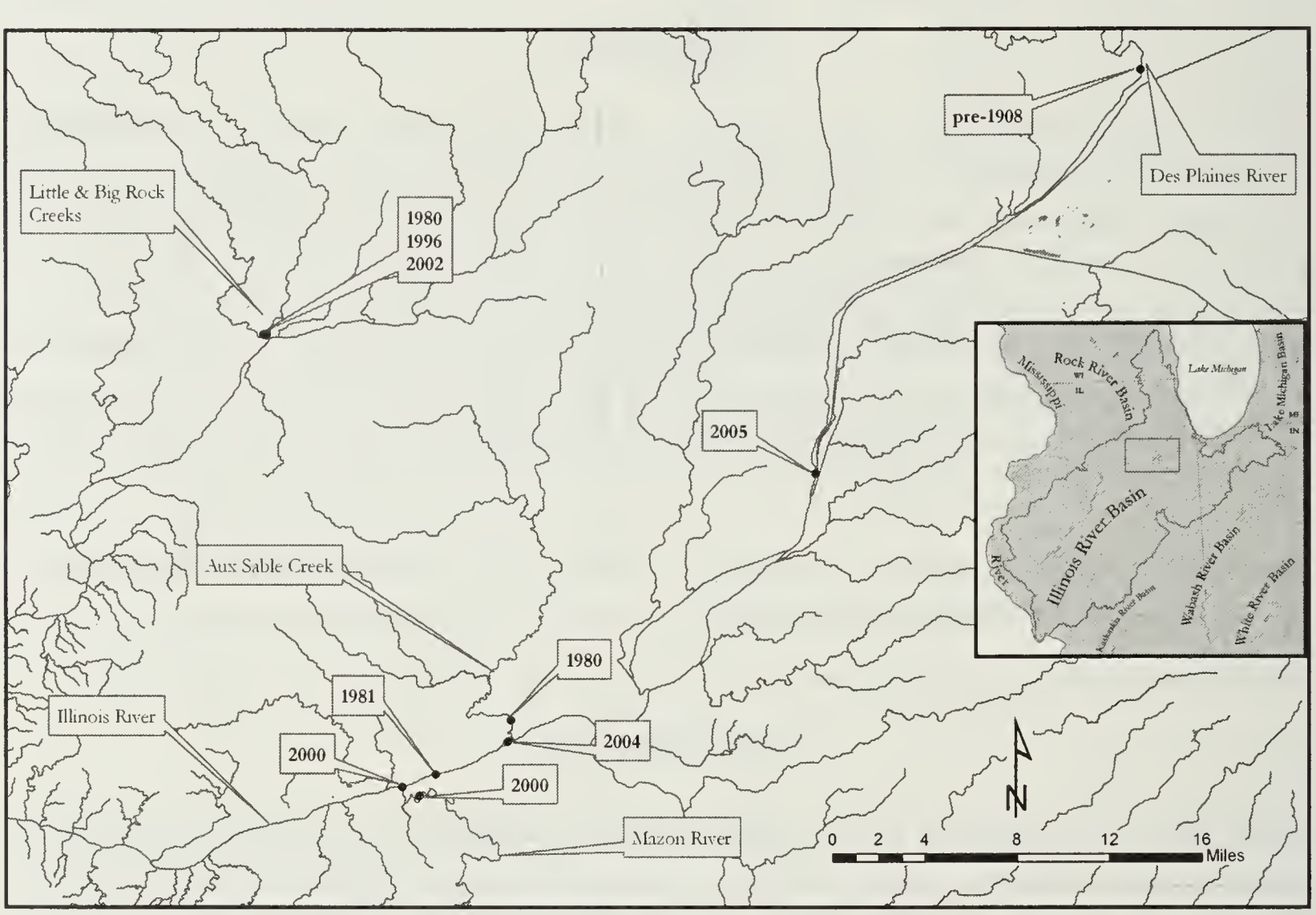

Figure 1. Distribution map of the freckled madtom *Noturus nocturnus* near Chicago, IL

Within Illinois, the freckled madtom is occasionally found in the central and southern portions of the state (INHS 2006). This species has been collected within the Chicago Region (Figure 1) in Aux Sable Creek (1980, 2004), Mazon River (2000), Illinois River near Morris (1981, 2000), and Little Rock Creek near Plano (1980, 1996, 2002). Aux Sable Creek, Mazon River, and Little Rock Creek are some of the highest rated streams in regards to quality in northeastern Illinois, whereas the Des Plaines River is one of the lowest rated rivers (S. Pescitelli, IDNR, pers. comm., 2005). The recent Des Plaines River sample is approximately 22 river miles upstream from the nearest collection, which is fragmented by two lock and dam structures.

According to Smith (1979), there is a record from the Des Plaines River near Brookfield, Illinois (pre-1908). Unfortunately, we have been unable to verify this record via specimen confirmation. The record is attributed to Stephen A. Forbes and Robert E. Richardson,

both of the Illinois Natural History Survey, who conducted most of their survey work between 1880 and 1905. Their *The Fishes of Illinois* (1920) states that the freckled madtom is rare in Illinois and was only found in the central portion of the state with the northernmost locality near Havana. They do not mention the Brookfield locality. Until other information on this old Des Plaines River record becomes available, we will assume it is valid in light of the collections made since the 1980s.

RESULTS AND DISCUSSION

A freckled madtom (*Noturus nocturnus*) was collected on 16 May 2005 during monthly monitoring for silver (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*) in the lower Des Plaines River. The exact locality was a deep, swift riffle in the Des Plaines River just above its confluence with the Chicago Sanitary and Ship Canal at the town of Joliet in Will County, IL. The specimen was collected through boat electro-fishing and then photographed and deposited in the Field Museum of Natural History's research collections (FMNH Accession number Z-19815). No other specimens were found despite additional surveys in the area throughout the rest of 2005.

The recently collected freckled madtom (Figure 2) measures 86.25 mm in standard length and 105.89 mm (4.17 inches) in total length. It weighs 14.60 grams (0.52 ounces). This is a larger than average-sized adult for this species, although some individuals can reach 150 mm (6 inches) in length (Smith, 1979; Burr and Mayden, 1982; Page and Burr, 1991; Cross and Collins, 1995). Madtoms are most easily distinguished from other catfishes by the shape of their adipose fin, which is long, low, and connected to their tail. The freckled madtom may be confused with three other sympatric madtom species within the Chicago Region: the stonecat (*Noturus flavus*), slender madtom (*Noturus exilis*), and tadpole madtom (*Noturus gyrinus*). The following key may be used to help correctly identify collections of these species:

1a. Upper and lower jaw even 2
1b. Upper jaw longer and protrudes over lower jaw 3

2a. Body elongate; dorsal, anal and caudal fins with black margins; side of body lacking vein-like lines ..... *Noturus exilis*
2b. Body stout and robust; dorsal, anal and caudal fin without black margins; body with vein-like lines ..... *Noturus gyrinus*

3a. Lower lip and chin without freckled pigment; tooth patch located on upper jaw with backward extensions ..... *Noturus flavus*
3b. Lower lip and chin with freckled pigment; tooth patch located on upper jaw lacking backward extensions ..... *Noturus nocturnus*

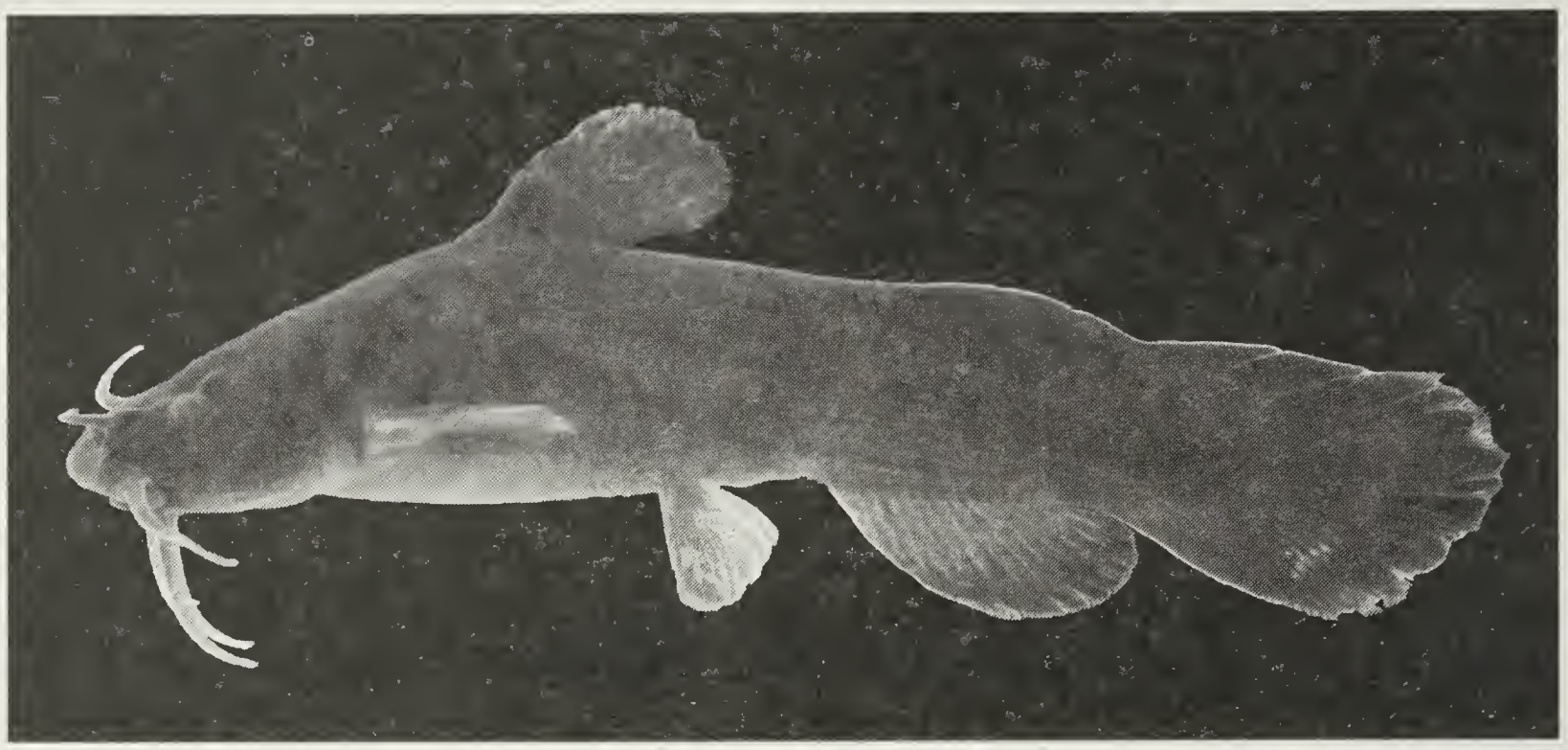

Figure 2. Freckled madtom *Noturus nocturnus* 105.89 mmTL, Des Plaines River, Will County, IL 16 May 2005 (FMNH Accession number Z-19815).

DISCUSSION

The Des Plaines River is routinely sampled by a variety of agencies. It is possible that the freckled madtom was present all along, but was overlooked for the past 100 years due to its difficulty to collect, a naturally sporadic occurrence (Pflieger, 1975; Mettee et al., 1996), and possible misidentification. Since the freckled madtom appears to be sensitive to water quality conditions, it is also possible that recent improvements to water quality have lead to local recolonization. The recolonization hypothesis requires the freckled madtom to move upstream through the Dresden Lock and Dam complex (21.7 feet high) and Brandon Lock and Dam complex (34 feet high). A dam would be an almost impossible barrier for a small catfish to pass, but locks that frequently fill and empty with water would not prevent the spread of small fishes. For example, the threadfin shad *Dorosoma petenense* is a species from Central America, Mexico, and the southern United States. It has been gradually been expanding its range northward and can now be found in the Des Plaines and Kankakee rivers (Laird and Page, 1996; INHS, 2006). A more extreme example is the american eel *Anguilla rostrata* that is born in the Sargasso Sea, Atlantic Ocean then occasionally swims all the way up the Mississippi and Illinois rivers into the Kankakee River (P.W. Willink, pers. observ.). These examples indicate that fishes can move upstream through multiple lock and dam complexes. The spread of the round goby *Neogobius melanostomus* from Lake Michigan to the Illinois River indicates that fishes can also move downstream through the same lock and dam complexes (USGS, 2006). There is no data on the seasonal movement patterns of the freckled madtom. Other madtom species tend to be largely sedentary (Burr and Stoeckel, 1999). Additional studies are needed to investigate the movement patterns and specific environmental preferences and sensitivities of the freckled madtom within the Chicago Region.

Although the occurrence of the freckled madtom in the Des Plaines River may be a sign of improved water quality, this does not imply that the Des Plaines River is pristine or has returned to its natural condition. There is still much work to be done in terms of

restoring habitat, connectivity and water quality. However, recent collections of the freckled madtom, an Iowa darter (*Etheostoma exile*) in Salt Creek (Gutmann, 2005), and a freshwater sponge (possibly *Spongilla aspinosa*) in the Chicago River (Murphy, 2005) are encouraging news for the region. The reappearance of the freckled madtom also demonstrates the importance of routine ichthyological sampling, particularly of the often-overlooked non-game fishes, as a way to monitor the status of our lakes and rivers. Additional knowledge and public awareness of our regional biodiversity will improve our ability to make decisions that impact our environment and way of life.

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